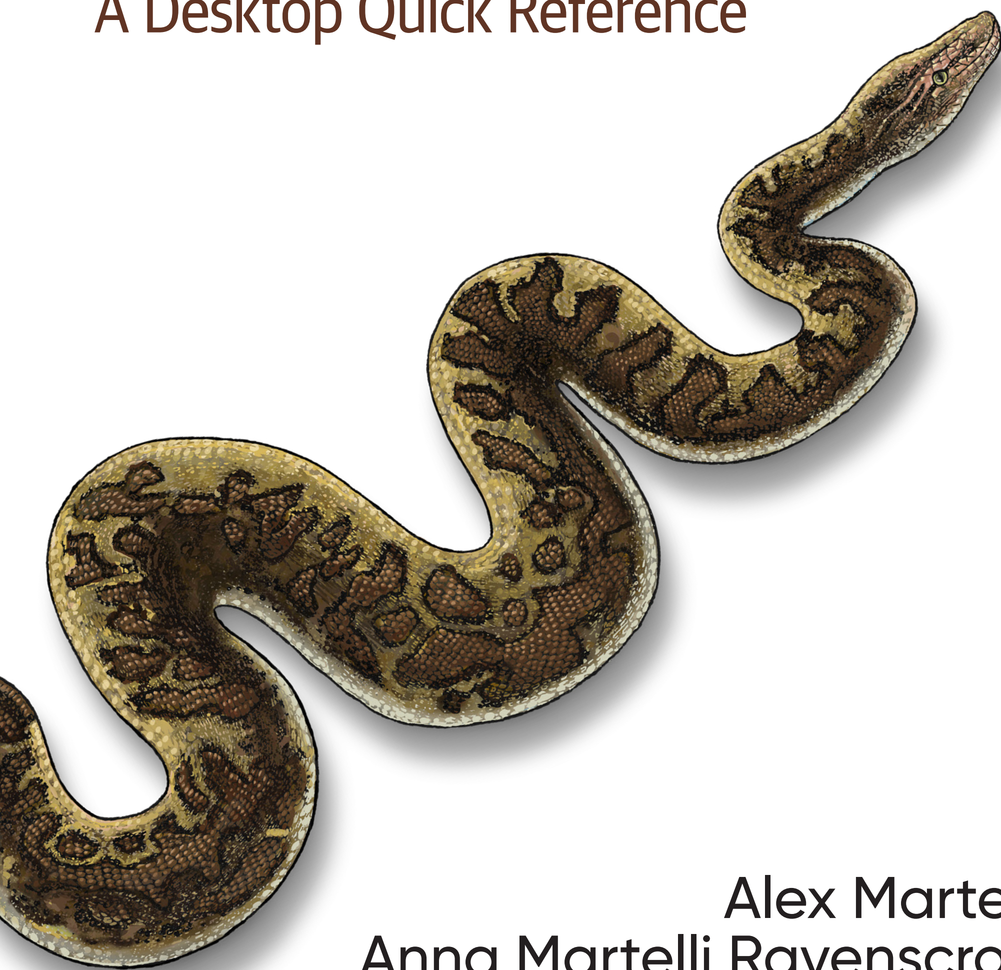
O'REILLY®

4th Edition
Covers Python 3.7 through 3.11

Python in a Nutshell

A Desktop Quick Reference



Alex Martelli,
Anna Martelli Ravenscroft,
Steve Holden & Paul McGuire

O'REILLY®

Python in a Nutshell

Python was recently ranked as today's most popular programming language on the TIOBE index, thanks, especially, to its broad applicability to design, prototyping, testing, deployment, and maintenance. With this updated fourth edition, you'll learn how to get the most out of Python, whether you're a professional programmer or someone who needs this language to solve problems in a particular field.

Carefully curated by recognized experts in Python, this new edition focuses on version 3.10, bringing this seminal work on the Python language fully up to date on five version releases, including coverage of recently released Python 3.11.

This handy guide will help you:

- **Learn how Python represents data and program as objects**
- **Understand the value and uses of type annotations**
- **Examine which language features appeared in which recent versions**
- **Discover how to use modern Python idiomatically**
- **Learn ways to structure Python projects appropriately**
- **Understand how to test, debug, and optimize Python code**

"Python in depth, up-to-date, accessible, and useful. An excellent modern reference with plenty of insight and advice that will satisfy everyone from early intermediates to experts."

—Mark Summerfield
Director of Qtrac Ltd.

The authors are four PSF Fellows, three of whom are Frank Willison Award recipients, recognized for numerous contributions to Python and its community. Their collective experience covers environments and platforms ranging from academic to startup to corporate to government.

Together they have compiled an authoritative reference for Python language syntax and features, the Python standard library, and selected third-party packages.

PROGRAMMING

US $89.99 CAN $112.99
ISBN: 978-1-098-11355-1

PYTHON IN A NUTSHELL

A Desktop Quick Reference

Fourth Edition

Alex Martelli, Anna Martelli Ravenscroft,
Steve Holden, and Paul McGuire

Beijing • Boston • Farnham • Sebastopol • Tokyo

O'REILLY®

Python in a Nutshell

by Alex Martelli, Anna Martelli Ravenscroft, Steve Holden, and Paul McGuire

Printed in the United States of America.

Published by O'Reilly Media, Inc., 1005 Gravenstein Highway North, Sebastopol, CA 95472.

O'Reilly books may be purchased for educational, business, or sales promotional use. Online editions are also available for most titles (*http://oreilly.com*). For more information, contact our corporate/institutional sales department: 800-998-9938 or *corporate@oreilly.com*.

Acquisitions Editor: Brian Guerin
Development Editor: Angela Rufino
Production Editor: Christopher Faucher
Copyeditor: Rachel Head
Proofreader: Sonia Saruba
Indexer: Judith McConville
Interior Designer: David Futato
Cover Designer: Karen Montgomery
Illustrator: O'Reilly Media, Inc.

March 2003:	First Edition
July 2006:	Second Edition
April 2017:	Third Edition
January 2023:	Fourth Edition

Revision History for the Fourth Edition

2023-01-09: First Release

See *https://www.oreilly.com/catalog/errata.csp?isbn=0636920602804* for release details.

978-1-098-11355-1

[LSI]

Table of Contents

Preface

The Python programming language reconciles many apparent contradictions: elegant yet pragmatic, simple yet powerful, it's very high-level yet doesn't get in your way when you need to fiddle with bits and bytes, and it's suitable for novice programmers and great for experts, too.

This book is intended for programmers with some previous exposure to Python, as well as experienced programmers coming to Python for the first time from other languages. It provides a quick reference to Python itself, the most commonly used parts of its vast standard library, and a few of the most popular and useful third-party modules and packages. The Python ecosystem has grown so much in richness, scope, and complexity that a single volume can no longer reasonably hope to be encyclopedic. Still, the book covers a wide range of application areas, including web and network programming, XML handling, database interactions, and high-speed numeric computing. It also explores Python's cross-platform capabilities and the basics of extending Python and embedding it in other applications.

How To Use This Book

While you can read this volume linearly from the beginning, we also aim for it to be a useful reference for the working programmer. You may choose to use the index to locate items of interest, or to read specific chapters for coverage of their particular topics. However you use it, we sincerely hope you enjoy reading what represents the fruit of the best part of a year's work for the team.

The book has five parts, as follows.

Part I, Getting Started with Python

Chapter 1, "Introduction to Python"
: Covers the general characteristics of the Python language, its implementations, where to get help and information, how to participate in the Python community, and how to obtain and install Python on your computer(s) or run it in your browser.

Chapter 2, "The Python Interpreter"
: Covers the Python interpreter program, its command-line options, and how to use it to run Python programs and in interactive sessions. The chapter mentions text editors for editing Python programs and auxiliary programs for checking your Python sources, along with some full-fledged integrated development environments, including IDLE, which comes free with standard Python. The chapter also covers running Python programs from the command line.

Part II, Core Python Language and Built-ins

Chapter 3, "The Python Language"
: Covers Python syntax, built-in data types, expressions, statements, control flow, and how to write and call functions.

Chapter 4, "Object-Oriented Python"
: Covers object-oriented programming in Python.

Chapter 5, "Type Annotations"
: Covers how to add type information to your Python code, to gain type hinting and autocomplete help from modern code editors and support static type checking from type checkers and linters.

Chapter 6, "Exceptions"
: Covers how to use exceptions for errors and special situations, logging, and how to write code to automatically clean up when exceptions occur.

Chapter 7, "Modules and Packages"
: Covers how Python lets you group code into modules and packages, how to define and import modules, and how to install third-party Python packages. This chapter also covers working with virtual environments to isolate project dependencies.

Chapter 8, "Core Built-ins and Standard Library Modules"
: Covers built-in data types and functions, and some of the most fundamental modules in the Python standard library (roughly speaking, the set of modules supplying functionality that, in some other languages, is built into the language itself).

Chapter 9, "Strings and Things"
: Covers Python's facilities for processing strings, including Unicode strings, bytestrings, and string literals.

Chapter 10, "Regular Expressions"
: Covers Python's support for regular expressions.

Part III, Python Library and Extension Modules

Chapter 11, "File and Text Operations"
: Covers dealing with files and text with many modules from Python's standard library and platform-specific extensions for rich text I/O. This chapter also covers issues regarding internationalization and localization.

Chapter 12, "Persistence and Databases"
: Covers Python's serialization and persistence mechanisms and its interfaces to DBM databases and relational (SQL-based) databases, particularly the handy SQLite that comes with Python's standard library.

Chapter 13, "Time Operations"
: Covers dealing with times and dates in Python, with the standard library and third-party extensions.

Chapter 14, "Customizing Execution"
: Covers ways to achieve advanced execution control in Python, including execution of dynamically generated code and control of garbage collection. This chapter also covers some Python internal types, and the specific issue of registering "cleanup" functions to execute at program termination time.

Chapter 15, "Concurrency: Threads and Processes"
: Covers Python's functionality for concurrent execution, both via multiple threads running within one process and via multiple processes running on a single machine.[1] This chapter also covers how to access the process's environment, and how to access files via memory-mapping mechanisms.

Chapter 16, "Numeric Processing"
: Covers Python's features for numeric computations, both in standard library modules and in third-party extension packages; in particular, how to use decimal numbers or fractions instead of the default binary floating-point numbers. This chapter also covers how to get and use pseudorandom and truly random numbers, and how to speedily process whole arrays (and matrices) of numbers.

Chapter 17, "Testing, Debugging, and Optimizing"
: Covers Python tools and approaches that help you make sure that your programs are correct (i.e., that they do what they're meant to do), find and fix errors in your programs, and check and enhance your programs' performance. This chapter also covers the concept of warnings and the Python library module that deals with them.

1 The separate chapter on asynchronous programming in the third edition has been dropped in this edition, deferring to more thorough coverage of this growing topic in references found in Chapter 15.

Part IV, Network and Web Programming

Chapter 18, "Networking Basics"
Covers the basics of networking with Python.

Chapter 19, "Client-Side Network Protocol Modules"
Covers modules in Python's standard library to write network client programs, particularly for dealing with various network protocols from the client side, sending and receiving emails, and handling URLs.

Chapter 20, "Serving HTTP"
Covers how to serve HTTP for web applications in Python, using popular third-party lightweight Python frameworks leveraging Python's WSGI standard interface to web servers.

Chapter 21, "Email, MIME, and Other Network Encodings"
Covers how to process email messages and other network-structured and encoded documents in Python.

Chapter 22, "Structured Text: HTML"
Covers popular third-party Python extension modules to process, modify, and generate HTML documents.

Chapter 23, "Structured Text: XML"
Covers Python library modules and popular extensions to process, modify, and generate XML documents.

Part V, Extending, Distributing, and Version Upgrade and Migration

Chapters 24 and 25 are included in summary form in the print edition of this book. You will find the full content of these chapters in the supporting online repository, described in "How to Contact Us" on page xv.

Chapter 24, "Packaging Programs and Extensions"
Covers tools and modules to package and share Python modules and applications.

Chapter 25, "Extending and Embedding Classic Python"
Covers how to code Python extension modules using Python's C API, Cython, and other tools.

Chapter 26, "v3.7 to v3.n Migration"
Covers topics and best practices for planning and deploying version upgrades for Python users ranging from individuals to library maintainers to enterprise-wide deployment and support staff.

Appendix, "New Features and Changes in Python 3.7 Through 3.11"
Provides a detailed list of features and changes in Python language syntax and the standard library, by version.

Conventions Used in This Book

The following conventions are used throughout this book.

Reference Conventions

In the function/method reference entries, when feasible, each optional parameter is shown with a default value using the Python syntax *`name=value`*. Built-in functions need not accept named parameters, so parameter names may not be significant. Some optional parameters are best explained in terms of their presence or absence, rather than through default values. In such cases, we indicate that a parameter is optional by enclosing it in brackets (`[]`). When more than one argument is optional, brackets can be nested.

Version Conventions

This book covers changes and features in Python versions 3.7 through 3.11.

Python 3.7 serves as the base version for all tables and code examples, unless otherwise noted.[2] You will see these notations to indicate changes or features added and removed across the range of covered versions:

- **3.x+** marks a feature introduced in version 3.x, not available in prior versions.
- **-3.x** marks a feature removed in version 3.x, available only in prior versions.

Typographic Conventions

Please note that, for display reasons, our code snippets and samples may sometimes depart from PEP 8. We do not recommend taking such liberties in your code. Instead, use a utility like `black` to adopt a canonical layout style.

The following typographical conventions are used in this book:

Italic
: Used for file and directory names, program names, URLs, and to introduce new terms.

`Constant width`
: Used for command-line output and code examples, as well as for code elements that appear in the text, including methods, functions, classes, and modules.

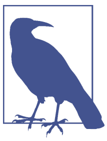
`Constant width italic`
: Used to show text to be replaced with user-supplied values in code examples and commands.

2 For example, to accommodate the widespread changes in Python 3.9 and 3.10 in type annotations, most of Chapter 5 uses Python 3.10 as the base version for features and examples.

`Constant width bold`

Used for commands to be typed at a system command line and to indicate code output in Python interpreter session examples. Also used for Python keywords.

This element signifies a tip or suggestion.



This element signifies a general note.

This element indicates a warning or caution.

Using Code Examples

This book is here to help you get your job done. In general, if example code is offered with this book, you may use it in your programs and documentation. You do not need to contact us for permission unless you're reproducing a significant portion of the code. For example, writing a program that uses several chunks of code from this book does not require permission. Selling or distributing examples from O'Reilly books does require permission. Answering a question by citing this book and quoting example code does not require permission. Incorporating a significant amount of example code from this book into your product's documentation does require permission.

We appreciate, but do not require, attribution. An attribution usually includes the title, author, publisher, and ISBN. For example: "*Python in a Nutshell*, 4th ed., by Alex Martelli, Anna Martelli Ravenscroft, Steve Holden, and Paul McGuire. Copyright 2023, 978-1-098-11355-1."

If you feel your use of code examples falls outside fair use or the permission given above, feel free to contact us at *permissions@oreilly.com*.

O'Reilly Online Learning

For more than 40 years, *O'Reilly Media* has provided technology and business training, knowledge, and insight to help companies succeed.

Our unique network of experts and innovators share their knowledge and expertise through books, articles, and our online learning platform. O'Reilly's online learning platform gives you on-demand access to live training courses, in-depth learning paths, interactive coding environments, and a vast collection of text and video from O'Reilly and 200+ other publishers. For more information, visit *https://oreilly.com*.

How to Contact Us

Please address comments and questions concerning this book to the publisher:

O'Reilly Media, Inc.
1005 Gravenstein Highway North
Sebastopol, CA 95472
800-998-9938 (in the United States or Canada)
707-829-0515 (international or local)
707-829-0104 (fax)

The book has its own GitHub repository, where we list errata, examples, and any additional information. The repository also contains the full content of Chapters 24 and 25, for which there was insufficient space in the printed volume. You will find it at *https://github.com/pynutshell/pynut4*.

We have tested and verified the information in this book to the best of our ability, but you may find that features have changed (or even that we have made mistakes!). Please let the publisher know about any errors you find, as well as your suggestions for future editions.

O'Reilly has a web page for this book, where they list errata, examples, and any additional information. You can access this page at *https://oreil.ly/python-nutshell-4e*.

To comment or ask technical questions about this book, send email to *pynut4@gmail.com*.

For news and information about our books and courses, visit *https://oreilly.com*.

Find us on LinkedIn: *https://linkedin.com/company/oreilly-media*.

Follow us on Twitter: *https://twitter.com/oreillymedia*.

Watch us on YouTube: *https://www.youtube.com/oreillymedia*.

Acknowledgments

Many thanks to O'Reilly editors and staff Amanda Quinn, Brian Guerin, Zan McQuade, and Kristen Brown. Special thanks to our editor, Angela Rufino, who did the heavy lifting to keep us on track to get this book completed on time! Also, thanks to our excellent copyeditor Rachel Head for helping us to seem more erudite than we are, and to our production editor, Christopher Faucher, for helping ensure the book looked its best in both printed and electronic formats.

Thanks to our hardworking tech reviewers, David Mertz, Mark Summerfield, and Pankaj Gaijar, who read through every explanation and example in the book's draft. Without them, this book would not have been as accurate.[3] All errors that remain are entirely our own.

Thanks also to Luciano Ramalho, the whole PyPy team, Sebastián Ramírez, Fabio Pliger, Miguel Grinberg, and the Python Packaging Authority team for their help on selected portions of the book, and to Google for its useful Workspace online collaboration tools, without which our intense communication (and coordination among authors on different continents!) would have been far less easy and efficient.

Last but by no means least, the authors and all readers of this book owe a huge debt of thanks to the core developers of the Python language itself, without whose heroic efforts there would be no need for this book.

3 Nor would it have so many footnotes!

1
Introduction to Python

Python is a well-established general-purpose programming language, first released by its creator, Guido van Rossum, in 1991. This stable and mature language is high-level, dynamic, object-oriented, and cross-platform—all very attractive characteristics. Python runs on macOS, most current Unix variants including Linux, Windows, and, with some tweaks, mobile platforms.[1]

Python offers high productivity for all phases of the software life cycle: analysis, design, prototyping, coding, testing, debugging, tuning, documentation, and, of course, maintenance. The language's popularity has seen steadily increasing growth for many years, becoming the TIOBE index leader in October 2021. Today, familiarity with Python is a plus for every programmer: it has snuck into most niches, with useful roles to play in any software solution.

Python provides a unique mix of elegance, simplicity, practicality, and sheer power. You'll quickly become productive with Python, thanks to its consistency and regularity, its rich standard library, and the many third-party packages and tools that are readily available for it. Python is easy to learn, so it is quite suitable if you are new to programming, yet is also powerful enough for the most sophisticated expert.

The Python Language

The Python language, while not minimalist, is spare, for good pragmatic reasons. Once a language offers one good way to express a design, adding other ways has, at best, modest benefits; the cost of language complexity, though, grows more than linearly with the number of features. A complicated language is harder to learn and

1 For Android, see *https://wiki.python.org/moin/Android*, and for iPhone and iPad, see Python for iOS and iPadOS.

master (and to implement efficiently and without bugs) than a simpler one. Complications and quirks in a language hamper productivity in software development, particularly in large projects, where many developers cooperate and, often, maintain code originally written by others.

Python is fairly simple, but not simplistic. It adheres to the idea that, if a language behaves a certain way in some contexts, it should ideally work similarly in all contexts. Python follows the principle that a language should not have "convenient" shortcuts, special cases, ad hoc exceptions, overly subtle distinctions, or mysterious and tricky under-the-covers optimizations. A good language, like any other well-designed artifact, must balance general principles with taste, common sense, and a lot of practicality.

Python is a general-purpose programming language: its traits are useful in almost any area of software development. There is no area where Python cannot be part of a solution. "Part" is important here; while many developers find that Python fills all of their needs, it does not have to stand alone. Python programs can cooperate with a variety of other software components, making it the right language for gluing together components in other languages. A design goal of the language is, and has long been, to "play well with others."

Python is a very high-level language (VHLL). This means that it uses a higher level of abstraction, conceptually further away from the underlying machine, than classic compiled languages such as C, C++, and Rust, traditionally called "high-level languages." Python is simpler, faster to process (both for humans and for tools), and more regular than classic high-level languages. This affords high programmer productivity, making Python a strong development tool. Good compilers for classic compiled languages can generate binary code that runs faster than Python. In most cases, however, the performance of Python-coded applications is sufficient. When it isn't, apply the optimization techniques covered in "Optimization" on page 541 to improve your program's performance while keeping the benefit of high productivity.

In terms of language level, Python is comparable to other powerful VHLLs like JavaScript, Ruby, and Perl. The advantages of simplicity and regularity, however, remain on Python's side.

Python is an object-oriented programming language, but it lets you program in both object-oriented and procedural styles, with a touch of functional programming too, mixing and matching as your application requires. Python's object-oriented features are conceptually similar to those of C++ but simpler to use.

The Python Standard Library and Extension Modules

There is more to Python programming than just the language: the standard library and other extension modules are almost as important for Python use as the language itself. The Python standard library supplies many well-designed, solid Python modules for convenient reuse. It includes modules for such tasks as representing data, processing text, interacting with the operating system and filesystem, and web programming, and works on all platforms supported by Python.

Extension modules, from the standard library or elsewhere, let Python code access functionality supplied by the underlying operating system or other software components, such as graphical user interfaces (GUIs), databases, and networks. Extensions also afford great speed in computationally intensive tasks such as XML parsing and numeric array computations. Extension modules that are not coded in Python, however, do not necessarily enjoy the same cross-platform portability as pure Python code.

You can write extension modules in lower-level languages to optimize performance for small, computationally intensive parts that you originally prototyped in Python. You can also use tools such as Cython, ctypes, and CFFI to wrap existing C/C++ libraries into Python extension modules, as covered in "Extending Python Without Python's C API" in Chapter 25 (available online). You can also embed Python in applications coded in other languages, exposing application functionality to Python via app-specific Python extension modules.

This book documents many modules, from the standard library and other sources, for client- and server-side network programming, databases, processing text and binary files, and interacting with operating systems.

Python Implementations

At the time of this writing, Python has two full production-quality implementations (CPython and PyPy) and several newer, high-performance ones in somewhat earlier stages of development, such as Nuitka, RustPython, GraalVM Python, and Pyston, which we do not cover further. In "Other Developments, Implementations, and Distributions" on page 5 we also mention some other, even earlier-stage implementations.

This book primarily addresses CPython, the most widely used implementation, which we often call just "Python" for simplicity. However, the distinction between a language and its implementations is important!

CPython

Classic Python—also known as CPython, often just called Python—is the most up-to-date, solid, and complete production-quality implementation of Python. It is the "reference implementation" of the language. CPython is a bytecode compiler, interpreter, and set of built-in and optional modules, all coded in standard C.

CPython can be used on any platform where the C compiler complies with the ISO/IEC 9899:1990 standard[2] (i.e., all modern, popular platforms). In "Installation" on page 14, we explain how to download and install CPython. All of this book, except a few sections explicitly marked otherwise, applies to CPython. As of this writing, CPython's current version, just released, is 3.11.

PyPy

PyPy is a fast and flexible implementation of Python, coded in a subset of Python itself, able to target several lower-level languages and virtual machines using advanced techniques such as type inferencing. PyPy's greatest strength is its ability to generate native machine code "just in time" as it runs your Python program; it has substantial advantages in execution speed. PyPy currently implements 3.8 (with 3.9 in beta).

Choosing Between CPython, PyPy, and Other Implementations

If your platform, as most are, is able to run CPython, PyPy, and several of the other Python implementations we mention, how do you choose among them? First of all, don't choose prematurely: download and install them all. They coexist without problems, and they're all free (some of them also offer commercial versions with added value such as tech support, but the respective free versions are fine, too). Having them all on your development machine costs only some download time and a little disk space, and lets you compare them directly. That said, here are a few general tips.

If you need a custom version of Python, or high performance for long-running programs, consider PyPy (or, if you're OK with versions that are not quite production-ready yet, one of the others we mention).

To work mostly in a traditional environment, CPython is an excellent fit. If you don't have a strong alternative preference, start with the standard CPython reference implementation, which is most widely supported by third-party add-ons and extensions and offers the most up-to-date version.

In other words, to experiment, learn, and try things out, use CPython. To develop and deploy, your best choice depends on the extension modules you want to use and how you want to distribute your programs. CPython, by definition, supports all Python extensions; however, PyPy supports most extensions, and it can often be faster for long-running programs thanks to just-in-time compilation to machine code—to check on that, benchmark your CPython code against PyPy (and, to be sure, other implementations as well).

---

2 Python versions from 3.11 use "C11 without optional features" and specify that "the public API should be compatible with C++."

CPython is most mature: it has been around longer, while PyPy (and the others) are newer and less proven in the field. The development of CPython versions proceeds ahead of that of other implementations.

PyPy, CPython, and other implementations we mention are all good, faithful implementations of Python, reasonably close to each other in terms of usability and performance. It is wise to become familiar with the strengths and weaknesses of each, and then choose optimally for each development task.

Other Developments, Implementations, and Distributions

Python has become so popular that several groups and individuals have taken an interest in its development and have provided features and implementations outside the core development team's focus.

Nowadays, most Unix-based systems include Python—typically version 3.*x* for some value of *x*—as the "system Python." To get Python on Windows or macOS, you usually download and run an installer (see also "macOS" on page 16.) If you are serious about software development in Python, the first thing you should do is *leave your system-installed Python alone!* Quite apart from anything else, Python is increasingly used by some parts of the operating system itself, so tweaking the Python installation could lead to trouble.

Thus, even if your system comes with a "system Python," consider installing one or more Python implementations to freely use for your development convenience, safe in the knowledge that nothing you do will affect the operating system. We also strongly recommend the use of *virtual environments* (see "Python Environments" on page 237) to isolate projects from each other, letting them have what might otherwise be conflicting dependencies (e.g., if two of your projects require different versions of the same third-party module). Alternatively, it is possible to locally install multiple Pythons side by side.

Python's popularity has led to the creation of many active communities, and the language's ecosystem is very active. The following sections outline some of the more interesting developments: note that our failure to include a project here reflects limitations of space and time, rather than implying any disapproval!

Jython and IronPython

Jython, supporting Python on top of a JVM, and IronPython, supporting Python on top of .NET, are open source projects that, while offering production-level quality for the Python versions they support, appear to be "stalled" at the time of this writing, since the latest versions they support are substantially behind CPython's. Any "stalled" open source project could, potentially, come back to life again: all it takes is one or more enthusiastic, committed developers to devote themselves to "reviving" it. As an alternative to Jython for the JVM, you might also consider GraalVM Python, mentioned earlier.

Numba

Numba is an open source just-in-time (JIT) compiler that translates a subset of Python and NumPy. Given its strong focus on numeric processing, we mention it again in Chapter 16.

Pyjion

Pyjion is an open source project, originally started by Microsoft, with the key goal of adding an API to CPython to manage JIT compilers. Secondary goals include offering a JIT compiler for Microsoft's open source CLR environment (which is part of .NET) and a framework to develop JIT compilers. Pyjion does not *replace* CPython; rather, it is a module that you import from CPython (it currently requires 3.10) that lets you translate CPython's bytecode, "just in time," into machine code for several different environments. Integration of Pyjion with CPython is enabled by PEP 523; however, since building Pyjion requires several tools in addition to a C compiler (which is all it takes to build CPython), the Python Software Foundation (PSF) will likely never bundle Pyjion into the CPython releases it distributes.

IPython

IPython enhances CPython's interactive interpreter to make it more powerful and convenient. It allows abbreviated function call syntax, and extensible functionality known as *magics* introduced by the percent (`%`) character. It also provides shell escapes, allowing a Python variable to receive the result of a shell command. You can use a question mark to query an object's documentation (or two question marks for extended documentation); all the standard features of the Python interactive interpreter are also available.

IPython has made particular strides in the scientific and data-focused world, and has slowly morphed (through the development of IPython Notebook, now refactored and renamed Jupyter Notebook, discussed in "Jupyter" on page 31) into an interactive programming environment that, among snippets of code,[3] also lets you embed commentary in literate programming style (including mathematical notation) and show the output of executing code, optionally with advanced graphics produced by such subsystems as `matplotlib` and `bokeh`. An example of `matplotlib` graphics embedded in a Jupyter Notebook is shown in the bottom half of Figure 1-1. Jupyter/IPython is one of Python's prominent success stories.

3 Which can be in many programming languages, not just Python.

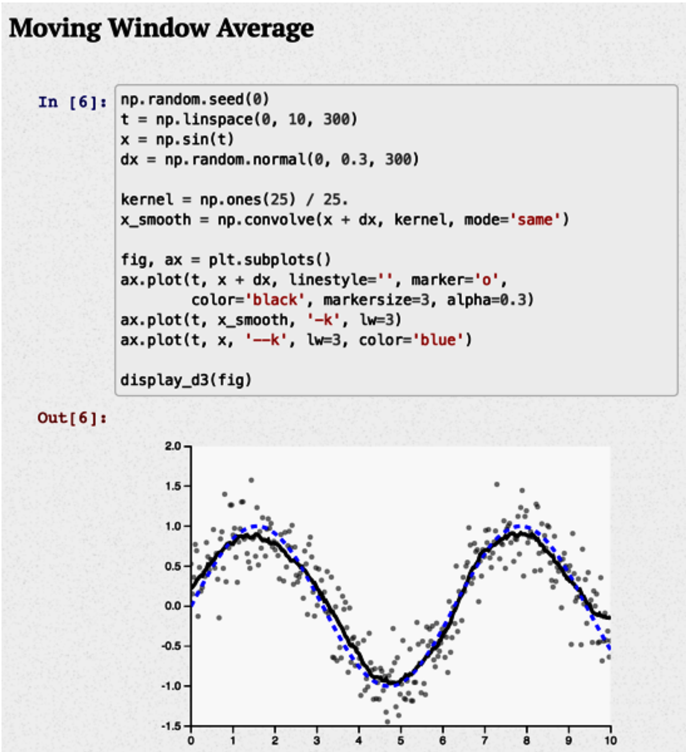


Figure 1-1. An example Jupyter Notebook with embedded matplotlib graph

MicroPython

The continued trend in miniaturization has brought Python well within the range of the hobbyist. Single-board computers like the Raspberry Pi and Beagle boards let you run Python in a full Linux environment. Below this level, there is a class of devices known as *microcontrollers*—programmable chips with configurable hardware—that extend the scope of hobby and professional projects, for example by making analog and digital sensing easy, enabling such applications as light and temperature measurements with little additional hardware.

Both hobbyists and professional engineers are making increasing use of these devices, which appear (and sometimes disappear) all the time. Thanks to the MicroPython project, the rich functionality of many such devices (micro:bit, Arduino, pyboard, LEGO® MINDSTORMS® EV3, HiFive, etc.) can now be programmed in (limited dialects of) Python. Of note at the time of writing is the introduction of the Raspberry Pi Pico. Given the success of the Raspberry Pi in the education world, and Pico's ability to run MicroPython, it seems that Python is consolidating its position as the programming language with the broadest range of applications.

MicroPython is a Python 3.4 implementation ("with selected features from later versions," to quote its docs) producing bytecode or executable machine code (many users will be happily unaware of the latter fact). It fully implements Python 3.4's syntax, but lacks most of the standard library. Special hardware driver modules let you control various parts of built-in hardware; access to Python's socket library lets devices interact with network services. External devices and timer events can trigger code. Thanks to MicroPython, the Python language can fully play in the Internet of Things.

A device typically offers interpreter access through a USB serial port, or through a browser using the WebREPL protocol (we aren't aware of any fully working `ssh` implementations yet, though, so, take care to firewall these devices properly: *they should **not** be directly accessible across the internet without proper, strong precautions!*). You can program the device's power-on bootstrap sequence in Python by creating a *boot.py* file in the device's memory, and this file can execute arbitrary MicroPython code of any complexity.

Anaconda and Miniconda

One of the most successful Python distributions[4] in recent years is Anaconda. This open source package comes with a vast number[5] of preconfigured and tested extension modules in addition to the standard library. In many cases, you might find that it contains all the necessary dependencies for your work. If your dependencies aren't supported, you can also install modules with `pip`. On Unix-based systems, it installs very simply in a single directory: to activate it, just add the Anaconda *bin* subdirectory at the front of your shell `PATH`.

Anaconda is based on a packaging technology called `conda`. A sister implementation, Miniconda, gives access to the same extensions but does not come with them preloaded; it instead downloads them as required, making it a better choice for creating tailored environments. `conda` does not use the standard virtual environments, but contains equivalent facilities to allow separation of the dependencies for multiple projects.

pyenv: Simple support for multiple versions

The basic purpose of `pyenv` is to make it easy to access as many different versions of Python as you need. It does so by installing so-called *shim* scripts for each executable, which dynamically compute the version required by looking at various sources of information in the following order:

4 In fact, `conda`'s capabilities extend to other languages, and Python is simply another dependency.

5 250+ automatically installed with Anaconda, 7,500+ explicitly installable with **`conda install`**.

1. The `PYENV_VERSION` environment variable (if set).
2. The *.pyenv_version* file in the current directory (if present)—you can set this with the **`pyenv local`** command.
3. The first *.pyenv_version* file found when climbing the directory tree (if one is found).
4. The *version* file in the `pyenv` installation root directory—you can set this with the **`pyenv global`** command.

`pyenv` installs its Python interpreters underneath its home directory (normally *~/.pyenv*), and, once available, a specific interpreter can be installed as the default Python in any project directory. Alternatively (e.g., when testing code under multiple versions), you can use scripting to change the interpreter dynamically as the script proceeds.

The **`pyenv install -list`** command shows an impressive list of over 500 supported distributions, including PyPy, Miniconda, MicroPython, and several others, plus every official CPython implementation from 2.1.3 to (at the time of writing) 3.11.0rc1.

Transcrypt: Convert your Python to JavaScript

Many attempts have been made to make Python into a browser-based language, but JavaScript's hold has been tenacious. The Transcrypt system is a `pip`-installable Python package to convert Python code (currently, up to version 3.9) into browser-executable JavaScript. You have full access to the browser's DOM, allowing your code to dynamically manipulate window content and use JavaScript libraries.

Although it creates minified code, Transcrypt provides full sourcemaps that allow you to debug with reference to the Python source rather than the generated JavaScript. You can write browser event handlers in Python, mixing it freely with HTML and JavaScript. Python may never replace JavaScript as the embedded browser language, but Transcrypt means you might no longer need to worry about that.

Another very active project that lets you script your web pages with Python (up to 3.10) is Brython, and there are others yet: Skulpt, not quite up to Python 3 yet but moving in that direction; PyPy.js, ditto; Pyodide, currently supporting Python 3.10 and many scientific extensions, and centered on Wasm; and, most recently, Anaconda's PyScript, built on top of Pyodide. We describe several of these projects in more detail in "Running Python in the Browser" on page 30.

Licensing and Price Issues

CPython is covered by the Python Software Foundation License Version 2, which is GNU Public License (GPL) compatible but lets you use Python for any proprietary, free, or other open source software development, similar to BSD/Apache/MIT licenses. Licenses for PyPy and other implementations are similarly liberal. Anything you download from the main Python and PyPy sites won't cost you a penny. Further, these licenses do not constrain what licensing and pricing conditions you can use for software you develop using the tools, libraries, and documentation they cover.

However, not everything Python-related is free from licensing costs or hassles. Many third-party Python sources, tools, and extension modules that you can freely download have liberal licenses, similar to that of Python itself. Others are covered by the GPL or Lesser GPL (LGPL), constraining the licensing conditions you can place on derived works. Some commercially developed modules and tools may require you to pay a fee, either unconditionally or if you use them for profit.[6]

There is no substitute for careful examination of licensing conditions and prices. Before you invest time and energy into any software tool or component, check that you can live with its license. Often, especially in a corporate environment, such legal matters may involve consulting lawyers. Modules and tools covered in this book, unless we explicitly say otherwise, can be taken to be, at the time of this writing, freely downloadable, open source, and covered by a liberal license akin to Python's. However, we claim no legal expertise, and licenses can change over time, so double-checking is always prudent.

Python Development and Versions

Python is developed, maintained, and released by a team of core developers led by Guido van Rossum, Python's inventor, architect, and now "ex" Benevolent Dictator for Life (BDFL). This title meant that Guido had the final say on what became part of the Python language and standard library. Once Guido decided to retire as BDFL, his decision-making role was taken over by a small "Steering Council," elected for yearly terms by PSF members.

Python's intellectual property is vested in the PSF, a nonprofit corporation devoted to promoting Python, described in "Python Software Foundation" on page 13. Many PSF Fellows and members have commit privileges to Python's reference source repositories, as documented in the "Python Developer's Guide", and most Python committers are members or Fellows of the PSF.

Proposed changes to Python are detailed in public docs called Python Enhancement Proposals (PEPs). PEPs are debated by Python developers and the wider Python community, and finally approved or rejected by the Steering Council. (The Steering Council may take debates and preliminary votes into account but are not bound by them.) Hundreds of people contribute to Python development through PEPs, discussion, bug reports, and patches to Python sources, libraries, and docs.

The Python core team releases minor versions of Python (3.*x* for growing values of *x*), also known as "feature releases," currently at a pace of once a year.

6 A popular business model is *freemium*: releasing both a free version and a commercial "premium" version with tech support and, perhaps, extra features.

Each minor release (as opposed to bug-fix microreleases) adds features that make Python more powerful, but also takes care to maintain backward compatibility. Python 3.0, which was allowed to break backward compatibility in order to remove redundant "legacy" features and simplify the language, was first released in December 2008. Python 3.11 (the most recent stable version at the time of publication) was first released in October 2022.

Each minor release 3.*x* is first made available in alpha releases, tagged as 3.*x*a0, 3.*x*a1, and so on. After the alphas comes at least one beta release, 3.*x*b1, and after the betas, at least one release candidate, 3.*x*rc1. By the time the final release of 3.*x* (3.*x*.0) comes out, it is solid, reliable, and tested on all major platforms. Any Python programmer can help ensure this by downloading alphas, betas, and release candidates, trying them out, and filing bug reports for any problems that emerge.

Once a minor release is out, part of the attention of the core team switches to the next minor release. However, a minor release normally gets successive point releases (i.e., 3.*x*.1, 3.*x*.2, and so on), one every two months, that add no functionality but can fix errors, address security issues, port Python to new platforms, enhance documentation, and add tools and (100% backward compatible!) optimizations.

Python's backward compatibility is fairly good within major releases. You can find code and documentation online for all old releases of Python, and the Appendix contains a summary list of changes in each of the releases covered in this book.

Python Resources

The richest Python resource is the web: start at Python's home page, which is full of links to explore.

Documentation

Both CPython and PyPy come with good documentation. You can read CPython's manuals online (we often refer to these as "the online docs"), and various downloadable formats suitable for offline viewing, searching, and printing are also available. The Python documentation page contains additional pointers to a large variety of other documents. There is also a documentation page for PyPy, and you can find online FAQs for both Python and PyPy.

Python documentation for nonprogrammers

Most Python documentation (including this book) assumes some software development knowledge. However, Python is quite suitable for first-time programmers, so there are exceptions to this rule. Good introductory, free online texts for nonprogrammers include:

- Josh Cogliati's "Non-Programmers Tutorial for Python 3" (currently centered on Python 3.9)
- Alan Gauld's "Learning to Program" (currently centered on Python 3.6)

- Allen Downey's *Think Python*, 2nd edition (centered on an unspecified version of Python 3.*x*)

An excellent resource for learning Python (for nonprogrammers, and for less experienced programmers too) is the "Beginners' Guide to Python" wiki, which includes a wealth of links and advice. It's community curated, so it will stay up-to-date as available books, courses, tools, and so on keep evolving and improving.

Extension modules and Python sources

A good starting point to explore Python extension binaries and sources is the Python Package Index (still fondly known to a few of us old-timers as "The Cheese Shop," but generally referred to now as PyPI), which at the time of this writing offers more than 400,000 packages, each with descriptions and pointers.

The standard Python source distribution contains excellent Python source code in the standard library and in the *Tools* directory, as well as C source for the many built-in extension modules. Even if you have no interest in building Python from source, we suggest you download and unpack the Python source distribution (e.g., the latest stable release of Python 3.11) for the sole purpose of studying it; or, if you so choose, peruse the current bleeding-edge version of Python's standard library online.

Many Python modules and tools covered in this book also have dedicated sites. We include references to such sites in the appropriate chapters.

Books

Although the web is a rich source of information, books still have their place (if you didn't agree with us on this, we wouldn't have written this book, and you wouldn't be reading it). Books about Python are numerous. Here are a few we recommend (some cover older Python 3 versions, rather than current ones):

- If you know some programming but are just starting to learn Python, and you like graphical approaches to instruction, *Head First Python*, 2nd edition, by Paul Barry (O'Reilly) may serve you well. Like all the books in the Head First series, it uses graphics and humor to teach its subject.
- *Dive Into Python 3*, by Mark Pilgrim (Apress), teaches by example in a fast-paced and thorough way that is quite suitable for people who are already expert programmers in other languages.
- *Beginning Python: From Novice to Professional*, by Magnus Lie Hetland (Apress), teaches both via thorough explanations and by fully developing complete programs in various application areas.
- *Fluent Python*, by Luciano Ramalho (O'Reilly), is an excellent book for more experienced developers who want to use more Pythonic idioms and features.

Community

One of the greatest strengths of Python is its robust, friendly, welcoming community. Python programmers and contributors meet at conferences, "hackathons" (often known as *sprints* in the Python community), and local user groups; actively discuss shared interests; and help each other on mailing lists and social media. For a complete list of ways to connect, visit *https://www.python.org/community*.

Python Software Foundation

Besides holding the intellectual property rights for the Python programming language, the PSF promotes the Python community. It sponsors user groups, conferences, and sprints, and provides grants for development, outreach, and education, among other activities. The PSF has dozens of Fellows (nominated for their contributions to Python, including all of the Python core team, as well as three of the authors of this book); hundreds of members who contribute time, work, and money (including many who've earned Community Service Awards); and dozens of corporate sponsors. Anyone who uses and supports Python can become a member of the PSF.[7] Check out the membership page for information on the various membership levels, and on how to become a member of the PSF. If you're interested in contributing to Python itself, see the "Python Developer's Guide".

Workgroups

Workgroups are committees established by the PSF to do specific, important projects for Python. Here are some examples of active workgroups at the time of writing:

- The Python Packaging Authority (PyPA) improves and maintains the Python packaging ecosystem and publishes the "Python Packaging User Guide".
- The Python Education workgroup promotes education and learning with Python.
- The Diversity and Inclusion workgroup supports and facilitates the growth of a diverse and international community of Python programmers.

Python conferences

There are lots of Python conferences worldwide. General Python conferences include international and regional ones, such as PyCon and EuroPython, and other more local ones such as PyOhio and PyCon Italia. Topical conferences include SciPy and PyData. Conferences are often followed by coding sprints, where Python contributors get together for several days of coding focused on particular open source projects and abundant camaraderie. You can find a listing of conferences on

7 The Python Software Foundation runs significant infrastructure to support the Python ecosystem. Donations to the PSF are always welcome.

the Community Conferences and Workshops page. More than 17,000 videos of talks about Python, from more than 450 conferences, are available at the PyVideo site.

User groups and organizations

The Python community has local user groups on every continent except Antarctica[8]—more than 1,600 of them, according to the list on the LocalUserGroups wiki. There are Python meetups around the world. PyLadies is an international mentorship group, with local chapters, to promote women in Python; anyone with an interest in Python is welcome. NumFOCUS, a nonprofit charity promoting open practices in research, data, and scientific computing, sponsors the PyData conference and other projects.

Mailing lists

The Community Mailing Lists page has links to several Python-related mailing lists (and some Usenet groups, for those of us old enough to remember Usenet!). Alternatively, search Mailman to find active mailing lists covering a wide variety of interests. Python-related official announcements are posted to the python-announce list. To ask for help with specific problems, write to *help@python.org*. For help learning or teaching Python, write to *tutor@python.org*, or, better yet, join the list. For a useful weekly roundup of Python-related news and articles, subscribe to Python Weekly. You can also follow Python Weekly at *@python_discussions@mastodon.social*.

Social media

For an RSS feed of Python-related blogs, see Planet Python. If you're interested in tracking language developments, check out *discuss.python.org*—it sends useful summaries if you don't visit regularly. On Twitter, follow @ThePSF. Libera.Chat on IRC hosts several Python-related channels: the main one is `#python`. LinkedIn has many Python groups, including Python Web Developers. On Slack, join the PySlackers community. On Discord, check out Python Discord. Technical questions and answers about Python programming can also be found and followed on Stack Overflow under a variety of tags, including [python]. Python is currently the most active programming language on Stack Overflow, and many useful answers with illuminating discussions can be found there. If you like podcasts, check out Python podcasts, such as Python Bytes.

Installation

You can install the classic (CPython) and PyPy versions of Python on most platforms. With a suitable development system (C for CPython; PyPy, coded in Python itself, only needs CPython installed first), you can install Python versions from

8 We need to mobilize to get more penguins interested in our language!

the respective source code distributions. On popular platforms, you also have the recommended alternative of installing prebuilt binary distributions.

Installing Python if It Comes Preinstalled

If your platform comes with a preinstalled version of Python, you're still best advised to install a separate up-to-date version for your own code development. When you do, do *not* remove or overwrite your platform's original version: rather, install the new version alongside the first one. This way, you won't disturb any other software that is part of your platform: such software might rely on the specific Python version that came with the platform itself.

Installing CPython from a binary distribution is faster, saves you substantial work on some platforms, and is the only possibility if you have no suitable C compiler. Installing from source code gives you more control and flexibility, and is a must if you can't find a suitable prebuilt binary distribution for your platform. Even if you install from binaries, it's best to also download the source distribution, since it can include examples, demos, and tools that are usually missing from prebuilt binaries. We'll look at how to do both next.

Installing Python from Binaries

If your platform is popular and current, you'll easily find prebuilt, packaged binary versions of Python ready for installation. Binary packages are typically self-installing, either directly as executable programs or via appropriate system tools, such as the Red Hat Package Manager (RPM) on some versions of Linux, and the Microsoft Installer (MSI) on Windows. After downloading a package, install it by running the program and choosing installation parameters, such as the directory where Python is to be installed. In Windows, select the option labeled "Add Python 3.10 to PATH" to have the installer add the install location into the PATH in order to easily use Python at a command prompt (see "The python Program" on page 21).

You can get the "official" binaries from the Downloads page on the Python website: click the button labeled "Download Python 3.11.x" to download the most recent binary suitable for your browser's platform.

Many third parties supply free binary Python installers for other platforms. Installers exist for Linux distributions, whether your distribution is RPM-based (Red Hat, Fedora, Mandriva, SUSE, etc.) or Debian-based (including Ubuntu, probably the most popular Linux distribution at the time of this writing). The Other Platforms page provides links to binary distributions for now somewhat exotic platforms such as AIX, OS/2, RISC OS, IBM AS/400, Solaris, HP-UX, and so forth (often not the latest Python versions, given the now "quaint" nature of such platforms), as well as one for the very current iOS platform, the operating system of the popular iPhone and iPad devices.

Anaconda, mentioned earlier in this chapter, is a binary distribution including Python, plus the `conda` package manager, plus hundreds of third-party extensions, particularly for science, math, engineering, and data analysis. It's available for Linux, Windows, and macOS. Miniconda, also mentioned earlier in this chapter, is the same package but without all of those extensions; you can selectively install subsets of them with `conda`.

> **macOS**
> The popular third-party macOS open source package manager Homebrew offers, among many other open source packages, excellent versions of Python. `conda`, mentioned in "Anaconda and Miniconda" on page 8, also works well in macOS.

Installing Python from Source Code

To install CPython from source code, you need a platform with an ISO-compliant C compiler and tools such as `make`. On Windows, the normal way to build Python is with Visual Studio (ideally VS 2022, currently available to developers for free).

To download the Python source code, visit the Python Source Releases page (on the Python website, hover over Downloads in the menu bar and select "Source code") and choose your version.

The file under the link labeled "Gzipped source tarball" has a *.tgz* file extension; this is equivalent to *.tar.gz* (i.e., a *tar* archive of files, compressed by the popular `gzip` compressor). Alternatively, you can use the link labeled "XZ compressed source tarball" to get a version with an extension of *.tar.xz* instead of *.tgz*, compressed with the even more powerful `xz` compressor, if you have all the needed tools to deal with XZ compression.

Microsoft Windows

On Windows, installing Python from source code can be a chore unless you are familiar with Visual Studio and used to working in the text-oriented window known as the *command prompt*[9]—most Windows users prefer to simply download the prebuilt Python from the Microsoft Store.

If the following instructions give you any trouble, stick with installing Python from binaries, as described in the previous section. It's best to do a separate installation from binaries anyway, even if you also install from source. If you notice anything strange while using the version you installed from source, double-check with the installation from binaries. If the strangeness goes away, it must be due to some quirk in your installation from source, so you know you must double-check the details of how you chose to build the latter.

9 Or, in modern Windows versions, the vastly preferable Windows Terminal.

In the following sections, for clarity, we assume you have made a new folder called *%USERPROFILE%\py* (e.g., *c:\users\tim\py*), which you can do, for example, by typing the **`mkdir`** command in any command window. Download the source *.tgz* file—for example, *Python-3.11.0.tgz*—to that folder. Of course, you can name and place the folder as it best suits you: our name choice is just for expository purposes.

Uncompressing and unpacking the Python source code

You can uncompress and unpack a *.tgz* or *.tar.xz* file with, for example, the free program 7-Zip. Download the appropriate version from the Download page, install it, and run it on the *.tgz* file (e.g., *c:\users\alex\py\Python-3.11.0.tgz*) that you downloaded from the Python website. Assuming you downloaded this file into your *%USERPROFILE%\py* folder (or moved it there from *%USERPROFILE%\downloads*, if necessary), you will now have a folder called *%USERPROFILE%\py\Python-3.11.0* or similar, depending on the version you downloaded. This is the root of a tree that contains the entire standard Python distribution in source form.

Building the Python source code

Open the *readme.txt* file located in the *PCBuild* subdirectory of this root folder with any text editor, and follow the detailed instructions found there.

Unix-Like Platforms

On Unix-like platforms, installing Python from source code is generally simple.[10] In the following sections, for clarity, we assume you have created a new directory named *~/py* and downloaded the source *.tgz* file—for example, *Python-3.11.0.tgz*—to that directory. Of course, you can name and place the directory as it best suits you: our name choice is just for expository purposes.

Uncompressing and unpacking the Python source code

You can uncompress and unpack a *.tgz* or *.tar.xz* file with the popular GNU version of `tar`. Just type the following at a shell prompt:

```
$ cd ~/py && tar xzf Python-3.11.0.tgz
```

You now have a directory called *~/py/Python-3.11.0* or similar, depending on the version you downloaded. This is the root of a tree that contains the entire standard Python distribution in source form.

10 Most problems with source installations concern the absence of various supporting libraries, which may cause some features to be missing from the built interpreter. The "Python Developers' Guide" explains how to handle dependencies on various platforms. *build-python-from-source.com* is a helpful site that shows you all the commands necessary to download, build, and install a specific version of Python, plus most of the needed supporting libraries on several Linux platforms.

Configuring, building, and testing

You'll find detailed notes in the *README* file inside this directory, under the heading "Build instructions," and we recommend you study those notes. In the simplest case, however, all you need may be to give the following commands at a shell prompt:

```
$ cd ~/py/Python-3.11/0
$ ./configure
    [configure writes much information, snipped here]
$ make
    [make takes quite a while and emits much information, snipped here]
```

If you run **`make`** without first running **`./configure`**, **`make`** implicitly runs **`./configure`**. When **`make`** finishes, check that the Python you have just built works as expected:

```
$ make test
    [takes quite a while, emits much information, snipped here]
```

Usually, **`make test`** confirms that your build is working, but also informs you that some tests have been skipped because optional modules were missing.

Some of the modules are platform-specific (e.g., some may work only on machines running SGI's ancient IRIX operating system); you don't need to worry about them. However, other modules may be skipped because they depend on other open source packages that are currently not installed on your machine. For example, on Unix, the module `_tkinter`—needed to run the Tkinter GUI package and the IDLE integrated development environment, which come with Python—can be built only if **`./configure`** can find an installation of Tcl/Tk 8.0 or later on your machine. See the *README* file for more details and specific caveats about different Unix and Unix-like platforms.

Building from source code lets you tweak your configuration in several ways. For example, you can build Python in a special way that helps you debug memory leaks when you develop C-coded Python extensions, covered in "Building and Installing C-Coded Python Extensions" in Chapter 25. **`./configure --help`** is a good source of information about the configuration options you can use.

Installing after the build

By default, **`./configure`** prepares Python for installation in */usr/local/bin* and */usr/local/lib*. You can change these settings by running **`./configure`** with the option **`--prefix`** before running **`make`**. For example, if you want a private installation of Python in the subdirectory *py311* of your home directory, run:

```
$ cd ~/py/Python-3.11.0
$ ./configure --prefix=~/py311
```

and continue with **make** as in the previous section. Once you're done building and testing Python, to perform the actual installation of all files, run the following command:[11]

```
$ make install
```

The user running **make install** must have write permissions on the target directories. Depending on your choice of target directories, and the permissions on those directories, you may need to **su** to *root, bin*, or some other user when you run **make install**. The common idiom for this purpose is **sudo make install**: if **sudo** prompts for a password, enter your current user's password, not *root*'s. An alternative, and recommended, approach is to install into a virtual environment, as covered in "Python Environments" on page 237.

11 Or **make altinstall**, if you want to avoid creating links to the Python executable and manual pages.

2
The Python Interpreter

To develop software systems in Python, you usually write text files that contain Python source code. You can do this using any text editor, including those we list in "Python Development Environments" on page 27. Then you process the source files with the Python compiler and interpreter. You can do this directly, within an integrated development environment (IDE), or via another program that embeds Python. The Python interpreter also lets you execute Python code interactively, as do IDEs.

The python Program

The Python interpreter program is run as **`python`** (it's named *python.exe* on Windows). The program includes both the interpreter itself and the Python compiler, which is implicitly invoked as needed on imported modules. Depending on your system, the program may have to be in a directory listed in your `PATH` environment variable. Alternatively, as with any other program, you can provide its complete pathname at a command (shell) prompt or in the shell script (or shortcut target, etc.) that runs it.[1]

On Windows, press the Windows key and start typing **`python`**. "Python 3.x" (the command-line version) appears, along with other choices, such as "IDLE" (the Python GUI).

1 This may involve using quotes if the pathname contains spaces—again, this depends on your operating system.

Environment Variables

Besides `PATH`, other environment variables affect the **`python`** program. Some of these have the same effects as options passed to **`python`** on the command line, as we show in the next section, but several environment variables provide settings not available via command-line options. The following list introduces some frequently used ones; for complete details, see the online docs:

`PYTHONHOME`
: The Python installation directory. A *lib* subdirectory, containing the Python standard library, must be under this directory. On Unix-like systems, standard library modules should be in *lib/python-3.x* for Python 3.*x*, where *x* is the minor Python version. If `PYTHONHOME` is not set, Python makes an informed guess about the installation directory.

`PYTHONPATH`
: A list of directories, separated by colons on Unix-like systems and by semicolons on Windows, from which Python can import modules. This list extends the initial value for Python's `sys.path` variable. We cover modules, importing, and `sys.path` in Chapter 7.

`PYTHONSTARTUP`
: The name of a Python source file to run each time an interactive interpreter session starts. No such file runs if you don't set this variable, or set it to the path of a file that is not found. The `PYTHONSTARTUP` file does not run when you run a Python script; it runs only when you start an interactive session.

How to set and examine environment variables depends on your operating system. In Unix, use shell commands, often within startup shell scripts. On Windows, press the Windows key and start typing **`environment var`**, and a couple of shortcuts appear: one for user environment variables, the other for system ones. On a Mac, you can work just as on other Unix-like systems, but you have more options, including a MacPython-specific IDE. For more information about Python on the Mac, see "Using Python on a Mac" in the online docs.

Command-Line Syntax and Options

The Python interpreter's command-line syntax can be summarized as follows:

```
[path]python {options} [-c command | -m module | file | -] {args}
```

Brackets (`[]`) enclose what's optional, braces (`{}`) enclose items of which zero or more may be present, and bars (`|`) mean a choice among alternatives. Python uses a slash (`/`) for filepaths, as in Unix.

Running a Python script at a command line can be as simple as:

```
$ python hello.py
Hello World
```

You can also explicitly provide the path to the script:

```
$ python ./hello/hello.py
 Hello World
```

The filename of the script can be an absolute or relative filepath, and need not have any specific extension (although it is conventional to use a *.py* extension).

`options` are case-sensitive short strings, starting with a hyphen, that ask **`python`** for nondefault behavior. **`python`** accepts only options that start with a hyphen (`-`). The most frequently used options are listed in Table 2-1. Each option's description gives the environment variable (if any) that, when set, requests that behavior. Many options have longer versions, starting with two hyphens, as shown by **`python -h`**. For full details, see the online docs.

Table 2-1. Frequently used `python` command-line options

Option	Meaning (and corresponding environment variable, if any)
`-B`	Don't save bytecode files to disk (`PYTHONDONTWRITEBYTECODE`)
`-c`	Gives Python statements within the command line
`-E`	Ignores all environment variables
`-h`	Shows the full list of options, then terminates
`-i`	Runs an interactive session after the file or command runs (`PYTHONINSPECT`)
`-m`	Specifies a Python module to run as the main script
`-O`	Optimizes bytecode (`PYTHONOPTIMIZE`)—note that this is an uppercase letter `O`, not the digit `0`
`-OO`	Like **`-O`**, but also removes docstrings from the bytecode
`-S`	Omits the implicit **`import`** `site` on startup (covered in "Per-Site Customization" on page 429)
`-t`, **`-tt`**	Issues warnings about inconsistent tab usage (**`-tt`** issues errors, rather than just warnings, for the same issues)
`-u`	Uses unbuffered binary files for standard output and standard error (`PYTHONUNBUFFERED`)
`-v`	Verbosely traces module import and cleanup actions (`PYTHONVERBOSE`)
`-V`	Prints the Python version number, then terminates
`-W arg`	Adds an entry to the warnings filter (see "The warnings Module" on page 538)
`-x`	Excludes (skips) the first line of the script's source

Use **`-i`** when you want to get an interactive session immediately after running some script, with top-level variables still intact and available for inspection. You do not need **`-i`** for normal interactive sessions, though it does no harm.

-O and **-OO** yield small savings of time and space in bytecode generated for modules you import, turning **assert** statements into no-operations, as covered in "The assert Statement" on page 219. **-OO** also discards documentation strings.[2]

After the options, if any, tell Python which script to run by adding the filepath to that script. Instead of a filepath, you can use **-c** *command* to execute a Python code string command. A *command* normally contains spaces, so you'll need to add quotes around it to satisfy your operating system's shell or command-line processor. Some shells (e.g., **bash**) let you enter multiple lines as a single argument, so that *command* can be a series of Python statements. Other shells (e.g., Windows shells) limit you to a single line; *command* can then be one or more simple statements separated by semicolons (`;`), as we discuss in "Statements" on page 39.

Another way to specify which Python script to run is with **-m** *module*. This option tells Python to load and run a module named ***module*** (or the *__main__.py* member of a package or ZIP file named *module*) from some directory that is part of Python's `sys.path`; this is useful with several modules from Python's standard library. For example, as covered in "The timeit module" on page 552, **-m timeit** is often the best way to perform micro-benchmarking of Python statements.

A hyphen (**-**), or the lack of any token in this position, tells the interpreter to read the program source from standard input—normally, an interactive session. You need a hyphen only if further arguments follow. *args* are arbitrary strings; the Python you run can access these strings as items of the list `sys.argv`.

For example, enter the following at a command prompt to have Python show the current date and time:

```
$ python -c "import time; print(time.asctime())"
```

You can start the command with just **python** (you do not have to specify the full path to Python) if the directory of the Python executable is in your `PATH` environment variable. (If you have multiple versions of Python installed, you can specify the version with, for example, **python3** or **python3.10**, as appropriate; then, the version used if you just say **python** is the one you installed most recently.)

The Windows py Launcher

On Windows, Python provides the **py** launcher to install and run multiple Python versions on a machine. At the bottom of the installer, you'll find an option to install the launcher for all users (it's checked by default). When you have multiple versions, you can select a specific version using **py** followed by a version option instead of the plain **python** command. Common **py** command options are listed in Table 2-2 (use **py -h** to see all the options).

2 This may affect code that parses docstrings for meaningful purposes; we suggest you avoid writing such code.

Table 2-2. Frequently used `py` command-line options

Option	Meaning
-2	Run the latest installed Python 2 version.
-3	Run the latest installed Python 3 version.
-3.*x* or **-3.*x*-*nn***	Run a specific Python 3 version. When referenced as just **-3.10**, uses the 64-bit version, or the 32-bit version if no 64-bit version is available. **-3.10-32** or **-3.10-64** picks a specific build when both are installed.
-0 or **--list**	List all installed Python versions, including an indication of whether a build is 32- or 64-bit, such as **3.10-64**.
-h	List all **py** command options, followed by standard Python help.

If no version option is given, **py** runs the latest installed Python.

For example, to show the local time using the installed Python 3.9 64-bit version, you can run this command:

```
C:\> py -3.9 -c "import time; print(time.asctime())"
```

(Typically, there is no need to give a path to **py**, since installing Python adds **py** to the system `PATH`.)

The PyPy Interpreter

PyPy, written in Python, implements its own compiler to generate LLVM intermediate code to run on an LLVM backend. The PyPy project offers some improvements over standard CPython, most notably in the areas of performance and multithreading. (At this writing, PyPy is up-to-date with Python 3.9.)

pypy may be run similarly to **python**:

```
[path]pypy {options} [-c command | file | - ] {args}
```

See the PyPy home page for installation instructions and complete up-to-date information.

Interactive Sessions

When you run **python** without a script argument, Python starts an interactive session and prompts you to enter Python statements or expressions. Interactive sessions are useful to explore, to check things out, and to use Python as a powerful, extensible interactive calculator. (Jupyter Notebook, discussed briefly at the end of this chapter, is like a "Python on steroids" specifically for interactive session usage.) This mode is often referred to as a *REPL*, or read–evaluate–print loop, since that's pretty much what the interpreter then does.

When you enter a complete statement, Python executes it. When you enter a complete expression, Python evaluates it. If the expression has a result, Python outputs a string representing the result and also assigns the result to the variable named `_` (a single underscore) so that you can immediately use that result in another expression. The prompt string is `>>>` when Python expects a statement or expression, and `...` when a statement or expression has been started but not completed. In particular, Python prompts with `...` when you have opened a parenthesis, bracket, or brace on a previous line and haven't closed it yet.

While working in the interactive Python environment, you can use the built-in **`help()`** function to drop into a help utility that offers useful information about Python's keywords and operators, installed modules, and general topics. When paging through a long help description, press **`q`** to return to the `help>` prompt. To exit the utility and return to the Python `>>>` prompt, type **`quit`**. You can also get help on specific objects at the Python prompt without entering the help utility by typing **`help(`*`obj`*`)`**, where *`obj`* is the program object you want more help with.

There are several ways you can end an interactive session. The most common are:

- Enter the end-of-file keystroke for your OS (Ctrl-Z on Windows, Ctrl-D on Unix-like systems).
- Execute either of the built-in functions `quit` or `exit`, using the form `quit()` or `exit()`. (Omitting the trailing `()` will display a message like "Use quit() or Ctrl-D (i.e., EOF) to exit," but will still leave you in the interpreter.)
- Execute the statement **`raise`** `SystemExit`, or call `sys.exit()` (we cover `SystemExit` and **`raise`** in Chapter 6, and the `sys` module in Chapter 8).

Use the Python Interactive Interpreter to Experiment

Trying out Python statements in the interactive interpreter is a quick way to experiment with Python and immediately see the results. For example, here is a simple use of the built-in `enumerate` function:

```
>>> print(list(enumerate("abc")))
[(0, 'a'), (1, 'b'), (2, 'c')]
```

The interactive interpreter is a good introductory platform to learn core Python syntax and features. (Experienced Python developers often open a Python interpreter to quickly check out an infrequently used command or function.)

Line-editing and history facilities depend in part on how Python was built: if the `readline` module was included, all features of the GNU `readline` library are available. Windows has a simple but usable history facility for interactive text mode programs like **`python`**.

In addition to the built-in Python interactive environment, and those offered as part of richer development environments covered in the next section, you can freely download other powerful interactive environments. The most popular one is *IPython*, covered in "IPython" on page 6, which offers a dazzling wealth of features. A simpler, lighter weight, but still quite handy alternative read-line interpreter is *bpython*.

Python Development Environments

The Python interpreter's built-in interactive mode is the simplest development environment for Python. It is primitive, but it's lightweight, has a small footprint, and starts fast. Together with a good text editor (as discussed in "Free Text Editors with Python Support" on page 28) and line-editing and history facilities, the interactive interpreter (or, alternatively, the much more powerful IPython/Jupyter command-line interpreter) is a usable development environment. However, there are several other development environments you can use.

IDLE

Python's Integrated Development and Learning Environment (IDLE) comes with standard Python distributions on most platforms. IDLE is a cross-platform, 100% pure Python application based on the Tkinter GUI. It offers a Python shell similar to the interactive Python interpreter, but richer. It also includes a text editor optimized to edit Python source code, an integrated interactive debugger, and several specialized browsers/viewers.

For more functionality in IDLE, install IdleX, a substantial collection of free third-party extensions.

To install and use IDLE on macOS, follow the specific instructions on the Python website.

Other Python IDEs

IDLE is mature, stable, easy, fairly rich, and extensible. There are, however, many other IDEs: cross-platform or platform specific, free or commercial (including commercial IDEs with free offerings, especially if you're developing open source software), standalone or add-ons to other IDEs.

Some of these IDEs sport features such as static analysis, GUI builders, debuggers, and so on. Python's IDE wiki page lists over 30, and points to many other URLs with reviews and comparisons. If you're an IDE collector, happy hunting!

We can't do justice to even a tiny subset of all the available IDEs. The free third-party plug-in PyDev for the popular cross-platform, cross-language modular IDE Eclipse has excellent Python support. Steve is a longtime user of Wing by Archaeopteryx, the most venerable Python-specific IDE. Paul's IDE of choice, and perhaps the single most popular third-party Python IDE today, is PyCharm by JetBrains. Thonny is a popular beginner's IDE, lightweight but full featured and easily installed on the Raspberry Pi (or just about any other popular platform). And not to be overlooked is Microsoft's Visual Studio Code, an excellent, very popular cross-platform IDE with support (via plug-ins) for a number of languages, including Python. If you use Visual Studio, check out PTVS, an open source plug-in that's particularly good at allowing mixed-language debugging in Python and C as and when needed.

Free Text Editors with Python Support

You can edit Python source code with any text editor, even simple ones such as Notepad on Windows or *ed* on Linux. Many powerful free editors support Python with extra features such as syntax-based colorization and automatic indentation. Cross-platform editors let you work in uniform ways on different platforms. Good text editors also let you run, from within the editor, tools of your choice on the source code you're editing. An up-to-date list of editors for Python can be found on the PythonEditors wiki, which lists dozens of them.

The very best for sheer editing power may be classic Emacs (see the Python wiki page for Python-specific add-ons). Emacs is not easy to learn, nor is it lightweight.[3] Alex's personal favorite[4] is another classic: Vim, Bram Moolenaar's improved version of the traditional Unix editor *vi*. It's arguably not *quite* as powerful as Emacs, but still well worth considering—it's fast, lightweight, Python programmable, and runs everywhere in both text mode and GUI versions. For excellent Vim coverage, see *Learning the vi and Vim Editors*, 8th edition, by Arnold Robbins and Elbert Hannah (O'Reilly); see the Python wiki page for Python-specific tips and add-ons. Steve and Anna use Vim too, and where it's available, Steve also uses the commercial editor Sublime Text, with good syntax coloring and enough integration to run your programs from inside the editor. For quick editing and executing of short Python scripts (and as a fast and lightweight general text editor, even for multimegabyte text files), SciTE is Paul's go-to editor.

Tools for Checking Python Programs

The Python compiler checks program syntax sufficiently to be able to run the program, or to report a syntax error. If you want more thorough checks of your Python code, you can download and install one or more third-party tools for the purpose. `pyflakes` is a very quick, lightweight checker: it's not thorough, but it doesn't import the modules it's checking, which makes using it fast and safe. At the other end of the spectrum, `pylint` is very powerful and highly configurable; it's not lightweight, but repays that by being able to check many style details in highly customizable ways based on editable configuration files.[5] `flake8` bundles `pyflakes` with other formatters and custom plug-ins, and can handle large codebases by

3 A great place to start is *Learning GNU Emacs*, 3rd edition (O'Reilly).

4 Not only as "an editor," but also as Alex's favorite "as close to an IDE as Alex will go" tool!

5 `pylint` also includes the useful `pyreverse` utility to autogenerate UML class and package diagrams directly from your Python code.

spreading work across multiple processes. `black` and its variant `blue` are intentionally less configurable; this makes them popular with widely dispersed project teams and open source projects in order to enforce a common Python style. To make sure you don't forget to run them, you can incorporate one or more of these checkers/formatters into your workflow using the `pre-commit` package.

For more thorough checking of Python code for proper type usages, use tools like `mypy`; see Chapter 5 for more on this topic.

Running Python Programs

Whatever tools you use to produce your Python application, you can see your application as a set of Python source files, which are normal text files that typically have the extension *.py*. A *script* is a file that you can run directly. A *module* is a file that you can import (as covered in Chapter 7) to provide some functionality to other files or interactive sessions. A Python file can be *both* a module (providing functionality when imported) *and* a script (OK to run directly). A useful and widespread convention is that Python files that are primarily intended to be imported as modules, when run directly, should execute some self-test operations, as covered in "Testing" on page 514.

The Python interpreter automatically compiles Python source files as needed. Python saves the compiled bytecode in a subdirectory called *__pycache__* within the directory with the module's source, with a version-specific extension annotated to denote the optimization level.

To avoid saving compiled bytecode to disk, you can run Python with the option **`-B`**, which can be handy when you import modules from a read-only disk. Also, Python does not save the compiled bytecode form of a script when you run the script directly; instead, Python recompiles the script each time you run it. Python saves bytecode files only for modules you import. It automatically rebuilds each module's bytecode file whenever necessary—for example, when you edit the module's source. Eventually, for deployment, you may package Python modules using tools covered in Chapter 24 (available online).

You can run Python code with the Python interpreter or an IDE.[6] Normally, you start execution by running a top-level script. To run a script, give its path as an argument to **python**, as covered in "The python Program" on page 21. Depending on your operating system, you can invoke **python** directly from a shell script or command file. On Unix-like systems, you can make a Python script directly executable by setting the file's permission bits `x` and `r`, and beginning the script with a *shebang* line, a line such as:

```
#!/usr/bin/env python
```

or some other line starting with `#!` followed by a path to the `python` interpreter program, in which case you can optionally add a single word of options—for example:

```
#!/usr/bin/python -OB
```

On Windows, you can use the same style `#!` line, in accordance with PEP 397, to specify a particular version of Python, so your scripts can be cross-platform between Unix-like and Windows systems. You can also run Python scripts with the usual Windows mechanisms, such as double-clicking their icons. When you run a Python script by double-clicking the script's icon, Windows automatically closes the text-mode console associated with the script as soon as the script terminates. If you want the console to linger (to allow the user to read the script's output on the screen), ensure the script doesn't terminate too soon. For example, use, as the script's last statement:

```
input('Press Enter to terminate')
```

This is not necessary when you run the script from a command prompt.

On Windows, you can also use the extension *.pyw* and interpreter program *pythonw.exe* instead of *.py* and *python.exe*. The *w* variants run Python without a text-mode console, and thus without standard input and output. This is good for scripts that rely on GUIs or run invisibly in the background. Use them only when a program is fully debugged, to keep standard output and error available for information, warnings, and error messages during development.

Applications coded in other languages may embed Python, controlling the execution of Python for their own purposes. We examine this briefly in "Embedding Python" in Chapter 25 (available online).

Running Python in the Browser

There are also options for running Python code within a browser session, executed in either the browser process or some separate server-based component. PyScript exemplifies the former approach, and Jupyter the latter.

6 Or online: Paul, for example, maintains a list of online Python interpreters.

PyScript

A recent development in the Python-in-a-browser endeavor is the release of PyScript by Anaconda. PyScript is built on top of Pyodide,[7] which uses WebAssembly to bring up a full Python engine in the browser. PyScript introduces custom HTML tags so that you can write Python code without having to know or use JavaScript. Using these tags, you can create a static HTML file containing Python code that will run in a remote browser, with no additional installed software required.

A simple PyScript "Hello, World!" HTML file might look like this:

```
<html>
<head>
    <link rel='stylesheet'
 href='https://pyscript.net/releases/2022.06.1/pyscript.css' />
    <script defer
 src='https://pyscript.net/releases/2022.06.1/pyscript.js'></script>
</head>
<body>
<py-script>
import time
print('Hello, World!')
print(f'The current local time is {time.asctime()}')
print(f'The current UTC time is {time.asctime(time.gmtime())}')
</py-script>
</body>
</html>
```

You can save this code snippet as a static HTML file and successfully run it in a client browser, even if Python isn't installed on your computer.

Changes Are Coming to PyScript

PyScript is still in early development at the time of publication, so the specific tags and APIs shown here are likely to change as the package undergoes further development.

For more complete and up-to-date information, see the PyScript website.

Jupyter

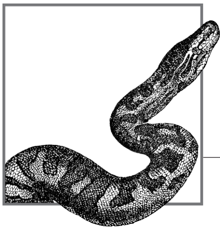
The extensions to the interactive interpreter in IPython (covered in "IPython" on page 6) were further extended by the Jupyter project, best known for the Jupyter Notebook, which offers Python developers a "literate programming" tool. A notebook server, typically accessed via a website, saves and loads each notebook, creating a Python kernel process to execute its Python commands interactively.

7 A great example of the synergy open source gets by projects "standing on the shoulders of giants" as an ordinary, everyday thing!

Notebooks are a rich environment. Each one is a sequence of cells whose contents may either be code or rich text formatted with the Markdown language extended with LaTeX, allowing complex mathematics to be included. Code cells can produce rich outputs too, including most popular image formats as well as scripted HTML. Special integrations adapt the `matplotlib` library to the web, and there are an increasing number of mechanisms for interaction with notebook code.

Further integrations allow notebooks to appear in other ways. For example, with the right extension, you can easily format a Jupyter notebook as a reveal.js slideshow for presentations in which the code cells can be interactively executed. Jupyter Book allows you to collect notebooks together as chapters and publish the collection as a book. GitHub allows browsing (but not executing) of uploaded notebooks (a special renderer provides correct formatting of the notebook).

There are many examples of Jupyter notebooks available on the internet. For a good demonstration of its features, take a look at the Executable Books website; notebooks underpin its publishing format.



3
The Python Language

This chapter is a guide to the Python language. To learn Python from scratch, we suggest you start with the appropriate links from the online docs and the resources mentioned in "Python documentation for nonprogrammers" on page 11. If you already know at least one other programming language well, and just want to learn specifics about Python, this chapter is for you. However, we're not trying to teach Python: we cover a lot of ground at a pretty fast pace. We focus on the rules, and only secondarily point out best practices and style; as your Python style guide, use PEP 8 (optionally augmented by extra guidelines such as those of "The Hitchhiker's Guide to Python", CKAN, and Google).

Lexical Structure

The *lexical structure* of a programming language is the set of basic rules that govern how you write programs in that language. It is the lowest-level syntax of the language, specifying such things as what variable names look like and how to denote comments. Each Python source file, like any other text file, is a sequence of characters. You can also usefully consider it a sequence of lines, tokens, or statements. These different lexical views complement each other. Python is very particular about program layout, especially lines and indentation: pay attention to this information if you are coming to Python from another language.

Lines and Indentation

A Python program is a sequence of *logical lines*, each made up of one or more *physical lines*. Each physical line may end with a comment. A hash sign (`#`) that is not inside a string literal starts a comment. All characters after the `#`, up to but excluding the line end, are the comment: Python ignores them. A line containing only whitespace, possibly with a comment, is a *blank line*: Python ignores it. In an interactive interpreter session, you must enter an empty physical line (without any whitespace or comment) to terminate a multiline statement.

In Python, the end of a physical line marks the end of most statements. Unlike in other languages, you don't normally terminate Python statements with a delimiter, such as a semicolon (`;`). When a statement is too long to fit on a physical line, you can join two adjacent physical lines into a logical line by ensuring that the first physical line does not contain a comment and ends with a backslash (`\`). More elegantly, Python also automatically joins adjacent physical lines into one logical line if an open parenthesis (`(`), bracket (`[`), or brace (`{`) has not yet been closed: take advantage of this mechanism to produce more readable code than you'd get with backslashes at line ends. Triple-quoted string literals can also span physical lines. Physical lines after the first one in a logical line are known as *continuation lines*. Indentation rules apply to the first physical line of each logical line, not to continuation lines.

Python uses indentation to express the block structure of a program. Python does not use braces, or other begin/end delimiters, around blocks of statements; indentation is the only way to denote blocks. Each logical line in a Python program is *indented* by the whitespace on its left. A *block* is a contiguous sequence of logical lines, all indented by the same amount; a logical line with less indentation ends the block. All statements in a block must have the same indentation, as must all clauses in a compound statement. The first statement in a source file must have no indentation (i.e., must not begin with any whitespace). Statements that you type at the interactive interpreter primary prompt, `>>>` (covered in "Interactive Sessions" on page 25), must also have no indentation.

Python treats each tab as if it was up to 8 spaces, so that the next character after the tab falls into logical column 9, 17, 25, and so on. Standard Python style is to use four spaces (*never* tabs) per indentation level.

If you must use tabs, Python does not allow mixing tabs and spaces for indentation.

Use Spaces, Not Tabs

Configure your favorite editor to expand a Tab keypress to four spaces, so that all Python source code you write contains just spaces, not tabs. This way, all tools, including Python itself, are consistent in handling indentation in your Python source files. Optimal Python style is to indent blocks by exactly four spaces; use no tab characters.

Character Sets

A Python source file can use any Unicode character, encoded by default as UTF-8. (Characters with codes between 0 and 127, the 7-bit *ASCII characters*, encode in UTF-8 into the respective single bytes, so an ASCII text file is a fine Python source file, too.)

You may choose to tell Python that a certain source file is written in a different encoding. In this case, Python uses that encoding to read the file. To let Python know that a source file is written with a nonstandard encoding, start your source file with a comment whose form must be, for example:

```
# coding: iso-8859-1
```

After `coding:`, write the name of an ASCII-compatible codec from the `codecs` module, such as `utf-8` or `iso-8859-1`. Note that this *coding directive* comment (also known as an *encoding declaration*) is taken as such only if it is at the start of a source file (possibly after the "shebang line" covered in "Running Python Programs" on page 29). Best practice is to use `utf-8` for all of your text files, including Python source files.

Tokens

Python breaks each logical line into a sequence of elementary lexical components known as *tokens*. Each token corresponds to a substring of the logical line. The normal token types are *identifiers*, *keywords*, *operators*, *delimiters*, and *literals*, which we cover in the following sections. You may freely use whitespace between tokens to separate them. Some whitespace separation is necessary between logically adjacent identifiers or keywords; otherwise, Python would parse them as a single longer identifier. For example, `ifx` is a single identifier; to write the keyword **`if`** followed by the identifier `x`, you need to insert some whitespace (typically only one space character, i.e., **`if`** `x`).

Identifiers

An *identifier* is a name used to specify a variable, function, class, module, or other object. An identifier starts with a letter (that is, any character that Unicode classifies as a letter) or an underscore (_), followed by zero or more letters, underscores, digits, or other characters that Unicode classifies as letters, digits, or combining marks (as defined in Unicode Standard Annex #31).

For example, in the Unicode Latin-1 character range, the valid leading characters for an identifier are:

```
ABCDEFGHIJKLMNOPQRSTUVWXYZ_abcdefghijklmnopqrstuvwxyz
ªµºÀÁÂÃÄÅÆÇÈÉÊËÌÍÎÏÐÑÒÓÔÕÖØÙÚÛÜÝÞßàáâãäåæçèéêëìíîïðñòóôõöøùúûüýþÿ
```

After the leading character, the valid identifier body characters are just the same, plus the digits and · (Unicode MIDDLE DOT) character:

```
0123456789ABCDEFGHIJKLMNOPQRSTUVWXYZ_abcdefghijklmnopqrstuvwxyz
ªµ·ºÀÁÂÃÄÅÆÇÈÉÊËÌÍÎÏÐÑÒÓÔÕÖØÙÚÛÜÝÞßàáâãäåæçèéêëìíîïðñòóôõöøùúûüýþÿ
```

Case is significant: lowercase and uppercase letters are distinct. Punctuation characters such as `@`, `$`, and `!` are not allowed in identifiers.

Beware of Using Unicode Characters That Are Homoglyphs

Some Unicode characters look very similar to, if not indistinguishable from, other characters. Such character pairs are called *homoglyphs*. For instance, compare the capital letter A and the capital Greek letter alpha (Α). These are actually two different letters that just look very similar (or identical) in most fonts. In Python, they define two different variables:

```
>>> A = 100
>>> # this variable is GREEK CAPITAL LETTER ALPHA:
>>> Α = 200
>>> print(A, Α)
100 200
```

If you want to make your Python code widely usable, we recommend a policy that all identifiers, comments, and documentation are written in English, avoiding, in particular, non-English homoglyph characters. For more information, see PEP 3131.

Unicode normalization strategies add further complexities (Python uses NFKC normalization when parsing identifiers containing Unicode characters). See Jukka K. Korpela's *Unicode Explained* (O'Reilly) and other technical information provided on the Unicode website and in the books that site references for more information.

Avoid Normalizable Unicode Characters in Identifiers

Python may create unintended aliases between variables when names contain certain Unicode characters, by internally converting the name as shown in the Python script to one using normalized characters. For example, the letters ª and º normalize to the ASCII lowercase letters a and o, so variables using these letters could clash with other variables:

```
>>> a, o = 100, 101
>>> ª, º = 200, 201
>>> print(a, o, ª, º)
200 201 200 201  # expected "100 101 200 201"
```

It is best to avoid using normalizable Unicode characters in your Python identifiers.

Normal Python style is to start class names with an uppercase letter, and most[1] other identifiers with a lowercase letter. Starting an identifier with a single leading underscore indicates by convention that the identifier is meant to be private. Starting an identifier with two leading underscores indicates a *strongly private* identifier; if the identifier also *ends* with two trailing underscores, however, this means that it's a language-defined special name. Identifiers composed of multiple words should

1 Identifiers referring to constants are all uppercase, by convention.

be all lowercase with underscores between words, as in `login_password`. This is sometimes referred to as *snake case*.

The Single Underscore (_) in the Interactive Interpreter

The identifier _ (a single underscore) is special in interactive interpreter sessions: the interpreter binds _ to the result of the last expression statement it has evaluated interactively, if any.

Keywords

Python has 35 *keywords*, or identifiers that it reserves for special syntactic uses. Like identifiers, keywords are case-sensitive. You cannot use keywords as regular identifiers (thus, they're sometimes known as "reserved words"). Some keywords begin simple statements or clauses of compound statements, while other keywords are operators. We cover all the keywords in detail in this book, either in this chapter or in Chapters 4, 6, and 7. The keywords in Python are:

and	**break**	**elif**	**from**	**is**	**pass**	**with**
as	**class**	**else**	**global**	**lambda**	**raise**	**yield**
assert	**continue**	**except**	**if**	**nonlocal**	**return**	**False**
async	**def**	**finally**	**import**	**not**	**try**	**None**
await	**del**	**for**	**in**	**or**	**while**	**True**

You can list them by importing the `keyword` module and printing `keyword.kwlist`.

3.9+ In addition, Python 3.9 introduced the concept of *soft keywords*, which are keywords that are context sensitive. That is, they are language keywords for some specific syntax constructs, but outside of those constructs they may be used as variable or function names, so they are not *reserved* words. No soft keywords were defined in Python 3.9, but Python 3.10 introduced the following soft keywords:

_ **case** **match**

You can list them from the `keyword` module by printing `keyword.softkwlist`.

Operators

Python uses nonalphanumeric characters and character combinations as operators. Python recognizes the following operators, which are covered in detail in "Expressions and Operators" on page 57:

```
+   -   *   /   %   **   //   <<   >>   &   @
|   ^   ~   <   <=   >   >=   !=   ==   @=   :=
```

You can use `@` as an operator (in matrix multiplication, covered in Chapter 16), although (pedantically speaking!) the character is actually a delimiter.

Delimiters

Python uses the following characters and combinations as delimiters in various statements, expressions, and list, dictionary, and set literals and comprehensions, among other purposes:

```
(    )    [    ]    {    }

,    :    .    =    ;    @

+=   -=   *=   /=   //=  %=

&=   |=   ^=   >>=  <<=  **=
```

The period (`.`) can also appear in floating-point literals (e.g., `2.3`) and imaginary literals (e.g., `2.3j`). The last two rows are the augmented assignment operators, which are delimiters but also perform operations. We discuss the syntax for the various delimiters when we introduce the objects or statements using them.

The following characters have special meanings as part of other tokens:

```
'  "  #  \
```

`'` and `"` surround string literals. `#` outside of a string starts a comment, which ends at the end of the current line. `\` at the end of a physical line joins the following physical line with it into one logical line; `\` is also an escape character in strings. The characters `$` and `?`, and all control characters[2] except whitespace, can never be part of the text of a Python program, except in comments or string literals.

Literals

A *literal* is the direct denotation in a program of a data value (a number, string, or container). The following are number and string literals in Python:

```
42                      # Integer literal
3.14                    # Floating-point literal
1.0j                    # Imaginary literal
'hello'                 # String literal
"world"                 # Another string literal
"""Good
night"""                # Triple-quoted string literal, spanning 2 lines
```

2 Control characters include nonprinting characters such as `\t` (tab) and `\n` (newline), both of which count as whitespace, and others such as `\a` (alarm, aka "beep") and `\b` (backspace), which are not whitespace.

Combining number and string literals with the appropriate delimiters, you can directly build many container types with those literals as values:

```
[42, 3.14, 'hello']     # List
[]                      # Empty list
100, 200, 300           # Tuple
(100, 200, 300)         # Tuple
()                      # Empty tuple
{'x':42, 'y':3.14}      # Dictionary
{}                      # Empty dictionary
{1, 2, 4, 8, 'string'}  # Set
# There is no literal form to denote an empty set; use set() instead
```


We cover the syntax for such container literals[3] in detail in "Data Types" on page 40, when we discuss the various data types Python supports. We refer to these expressions as literals throughout this book, as they describe literal (i.e., not requiring additional evaluation) values in the source code.

Statements

You can look at a Python source file as a sequence of simple and compound statements.

Simple statements

A *simple statement* is one that contains no other statements. A simple statement lies entirely within a logical line. As in many other languages, you may place more than one simple statement on a single logical line, with a semicolon (`;`) as the separator. However, using one statement per line is the usual and recommended Python style, and it makes programs more readable.

Any *expression* can stand on its own as a simple statement (we discuss expressions in "Expressions and Operators" on page 57). When you're working interactively, the interpreter shows the result of an expression statement you enter at the prompt (`>>>`) and binds the result to a global variable named `_` (underscore). Apart from interactive sessions, expression statements are useful only to call functions (and other *callables*) that have side effects (e.g., perform output, change arguments or global variables, or raise exceptions).

An *assignment* is a simple statement that assigns values to variables, as we discuss in "Assignment Statements" on page 53. An assignment in Python using the `=` operator is a statement and can never be part of an expression. To perform an assignment as part of an expression, you must use the `:=` (known as the "walrus") operator. You'll see some examples of using `:=` in "Assignment Expressions" on page 59.

3 "Container displays," per the online docs (e.g., `list_display`), but specifically ones with literal items.

Compound statements

A *compound statement* contains one or more other statements and controls their execution. A compound statement has one or more *clauses*, aligned at the same indentation. Each clause has a *header* starting with a keyword and ending with a colon (`:`), followed by a *body*, which is a sequence of one or more statements. Normally, these statements, also known as a *block*, are on separate logical lines after the header line, indented four spaces rightward. The block lexically ends when the indentation returns to that of the clause header (or further left from there, to the indentation of some enclosing compound statement). Alternatively, the body can be a single simple statement following the `:` on the same logical line as the header. The body may also consist of several simple statements on the same line with semicolons between them, but, as we've already mentioned, this is not good Python style.

Data Types

The operation of a Python program hinges on the data it handles. Data values in Python are known as *objects*; each object, aka *value*, has a *type*. An object's type determines which operations the object supports (in other words, which operations you can perform on the value). The type also determines the object's *attributes* and *items* (if any) and whether the object can be altered. An object that can be altered is known as a *mutable object*, while one that cannot be altered is an *immutable object*. We cover object attributes and items in "Object attributes and items" on page 53.

The built-in `type(`*`obj`*`)` function accepts any object as its argument and returns the type object that is the type of *`obj`*. The built-in function `isinstance(`*`obj, type`*`)` returns **`True`** when object *`obj`* has type *`type`* (or any subclass thereof); otherwise, it returns **`False`**. The *`type`* argument of `isinstance` may also be a tuple of types (**3.10+** or multiple types joined with the `|` operator), in which case it returns **`True`** if the type of *`obj`* matches any of the given types, or any subclasses of those types.

Python has built-in types for fundamental data types such as numbers, strings, tuples, lists, dictionaries, and sets, as covered in the following sections. You can also create user-defined types, known as *classes*, as discussed in "Classes and Instances" on page 115.

Numbers

The built-in numeric types in Python include integers, floating-point numbers, and complex numbers. The standard library also offers decimal floating-point numbers, covered in "The decimal Module" on page 500, and fractions, covered in "The fractions Module" on page 498. All numbers in Python are immutable objects; therefore, when you perform an operation on a number object, you produce a new number object. We cover operations on numbers, also known as arithmetic operations, in "Numeric Operations" on page 60.

Numeric literals do not include a sign: a leading `+` or `-`, if present, is a separate operator, as discussed in "Arithmetic Operations" on page 61.

Integer numbers

Integer literals can be decimal, binary, octal, or hexadecimal. A decimal literal is a sequence of digits in which the first digit is nonzero. A binary literal is `0b` followed by a sequence of binary digits (`0` or `1`). An octal literal is `0o` followed by a sequence of octal digits (`0` to `7`). A hexadecimal literal is `0x` followed by a sequence of hexadecimal digits (`0` to `9` and `A` to `F`, in either upper- or lowercase). For example:

```
1, 23, 3493                    # Decimal integer literals
0b010101, 0b110010, 0B01       # Binary integer literals
0o1, 0o27, 0o6645, 0O777       # Octal integer literals
0x1, 0x17, 0xDA5, 0xda5, 0Xff  # Hexadecimal integer literals
```

Integers can represent values in the range `±2**sys.maxsize`, or roughly $\pm10^{2.8e18}$.

Table 3-1 lists the methods supported by an `int` object *`i`*.

Table 3-1. `int` methods

`as_integer_ratio`	*`i`*`.as_integer_ratio()` **3.8+** Returns a tuple of two `int`s, whose exact ratio is the original integer value. (Since *`i`* is always `int`, the tuple is always `(`*`i`*`, 1)`; compare with `float.as_integer_ratio`.)
`bit_count`	*`i`*`.bit_count()` **3.10+** Returns the number of ones in the binary representation of `abs(`*`i`*`)`.
`bit_length`	*`i`*`.bit_length()` Returns the minimum number of bits needed to represent *`i`*. Equivalent to the length of the binary representation of `abs(`*`i`*`)`, after removing `'b'` and all leading zeros. `(0).bit_length()` returns `0`.
`from_bytes`	`int.from_bytes(`*`bytes_value`*`, `*`byteorder`*`, *, `*`signed`*`=`**`False`**`)` Returns an `int` from the bytes in *`bytes_value`* following the same argument usage as in `to_bytes`. (Note that `from_bytes` is a class method of `int`.)
`to_bytes`	*`i`*`.to_bytes(`*`length`*`, `*`byteorder`*`, *, `*`signed`*`=`**`False`**`)` Returns a `bytes` value *`length`* bytes in size representing the binary value of *`i`*. *`byteorder`* must be the `str` value `'big'` or `'little'`, indicating whether the return value should be big-endian (most significant byte first) or little-endian (least significant byte first). For example, `(258).to_bytes(2, 'big')` returns `b'\x01\x02'`, and `(258).to_bytes(2, 'little')` returns `b'\x02\x01'`. When *`i`* `< 0` and *`signed`* is **`True`**, `to_bytes` returns the bytes of *`i`* represented in two's complement. When *`i`* `< 0` and *`signed`* is **`False`**, `to_bytes` raises `OverflowError`.

Floating-point numbers

A floating-point literal is a sequence of decimal digits that includes a decimal point (`.`), an exponent suffix (`e` or `E`, optionally followed by `+` or `-`, followed by one or more digits), or both. The leading character of a floating-point literal cannot be `e` or `E`; it may be any digit or a period (`.`) followed by a digit. For example:

```
0., 0.0, .0, 1., 1.0, 1e0, 1.e0, 1.0E0  # Floating-point literals
```

A Python floating-point value corresponds to a C `double` and shares its limits of range and precision: typically 53 bits—about 15 digits—of precision on modern platforms. (For the exact range and precision of floating-point values on the platform where the code is running, and many other details, see the online documentation on `sys.float_info`.)

Table 3-2 lists the methods supported by a `float` object *f*.

Table 3-2. `float` methods

`as_integer_ratio`	`f.as_integer_ratio()` Returns a tuple of two `int`s, a numerator and a denominator, whose exact ratio is the original float value, *f*. For example: `>>> f=2.5` `>>> f.as_integer_ratio()` `(5, 2)`
`from_hex`	`float.from_hex(s)` Returns a `float` value from the hexadecimal `str` value *s*. *s* can be of the form returned by `f.hex()`, or simply a string of hexadecimal digits. When the latter is the case, `from_hex` returns `float(int(s, 16))`.
`hex`	`f.hex()` Returns a hexadecimal representation of *f*, with leading `0x` and trailing `p` and exponent. For example, `(99.0).hex()` returns `'0x1.8c00000000000p+6'`.
`is_integer`	`f.is_integer()` Returns a `bool` value indicating if *f* is an integer value. Equivalent to `int(f) == f`.

Complex numbers

A complex number is made up of two floating-point values, one each for the real and imaginary parts. You can access the parts of a complex object *z* as read-only attributes `z.real` and `z.imag`. You can specify an imaginary literal as any floating-point or integer decimal literal followed by a `j` or `J`:

```
0j, 0.j, 0.0j, .0j, 1j, 1.j, 1.0j, 1e0j, 1.e0j, 1.0e0j
```

The `j` at the end of the literal indicates the square root of `-1`, as commonly used in electrical engineering (some other disciplines use `i` for this purpose, but Python uses `j`). There are no other complex literals. To denote any constant complex number, add or subtract a floating-point (or integer) literal and an imaginary one. For example, to denote the complex number that equals 1, use expressions like `1+0j` or `1.0+0.0j`. Python performs the addition at compile time, so there's no need to worry about overhead.

A `complex` object *c* supports a single method:

`conjugate`	`c.conjugate()` Returns a new complex number `complex(c.real, -c.imag)` (i.e., the return value has *c*'s `imag` attribute with a sign change).

See "The math and cmath Modules" on page 488 for several other functions that use floats and complex numbers.

Underscores in numeric literals

To aid with visual assessment of the magnitude of a number, numeric literals can include single underscore (_) characters between digits or after any base specifier. It's not only decimal numeric constants that can benefit from this notational freedom, however, as these examples show:

```
>>> 100_000.000_0001, 0x_FF_FF, 0o7_777, 0b_1010_1010
(100000.0000001, 65535, 4095, 170)
```

There is no enforcement of location of the underscores (except that two may not occur consecutively), so `123_456` and `12_34_56` both represent the same `int` value as `123456`.

The Python Language

Sequences

A *sequence* is an ordered container of items, indexed by integers. Python has built-in sequence types known as strings (`bytes` or `str`), tuples, and lists. Library and extension modules provide other sequence types, and you can write others yourself (as discussed in "Sequences" on page 43). You can manipulate sequences in a variety of ways, as discussed in "Sequence Operations" on page 62.

Iterables

A Python concept that captures in abstract the iteration behavior of sequences is that of *iterables*, covered in "The for Statement" on page 84. All sequences are iterable: whenever we say you can use an iterable, you can use a sequence (for example, a list).

Also, when we say that you can use an iterable we usually mean a *bounded* iterable: an iterable that eventually stops yielding items. In general, sequences are bounded. Iterables can be unbounded, but if you try to use an unbounded iterable without special precautions, you could produce a program that never terminates, or one that exhausts all available memory.

Strings

Python has two built-in string types, `str` and `bytes`.[4] A `str` object is a sequence of characters used to store and represent text-based information. A `bytes` object stores and represents arbitrary sequences of binary bytes. Strings of both types in Python are *immutable*: when you perform an operation on strings, you always produce a new string object of the same type, rather than mutating an existing string. String objects provide many methods, as discussed in detail in "Methods of String Objects" on page 281.

A string literal can be quoted or triple-quoted. A quoted string is a sequence of zero or more characters within matching quotes, single (`'`) or double (`"`). For example:

```
'This is a literal string'
"This is another string"
```

The two different kinds of quotes function identically; having both lets you include one kind of quote inside of a string specified with the other kind, with no need to escape quote characters with the backslash character (`\`):

```
'I\'m a Python fanatic'     # You can escape a quote
"I'm a Python fanatic"      # This way may be more readable
```

Many (but far from all) style guides that pronounce on the subject suggest that you use single quotes when the choice is otherwise indifferent. The popular code formatter `black` prefers double quotes; this choice is controversial enough to have been the main inspiration for a "fork," `blue`, whose main difference from `black` is to prefer single quotes instead, as most of this book's authors do.

To have a string literal span multiple physical lines, you can use a `\` as the last character of a line to indicate that the next line is a continuation:

```
'A not very long string \
that spans two lines'       # Comment not allowed on previous line
```

You can also embed a newline in the string to make it contain two lines rather than just one:

```
'A not very long string\n\
that prints on two lines'   # Comment not allowed on previous line
```

A better approach, however, is to use a triple-quoted string, enclosed by matching triplets of quote characters (`'''`, or better, as mandated by PEP 8, `"""`). In a triple-quoted string literal, line breaks in the literal remain as newline characters in the resulting string object:

```
"""An even bigger
string that spans
three lines"""              # Comments not allowed on previous lines
```

4 There's also a `bytearray` object, covered shortly, which is a `bytes`-like "string" that *is* mutable.

You can start a triple-quoted literal with an escaped newline, to avoid having the first line of the literal string's content at a different indentation level from the rest. For example:

```
the_text = """\
First line
Second line
"""       # The same as "First line\nSecond line\n" but more readable
```

The only character that cannot be part of a triple-quoted string literal is an unescaped backslash, while a single-quoted string literal cannot contain unescaped backslashes, nor line ends, nor the quote character that encloses it. The backslash character starts an *escape sequence*, which lets you introduce any character in either kind of string literal. See Table 3-3 for a list of all of Python's string escape sequences.

Table 3-3. String escape sequences

Sequence	Meaning	ASCII / ISO code
`\`*<newline>*	Ignore end of line	None
`\\`	Backslash	`0x5c`
`\'`	Single quote	`0x27`
`\"`	Double quote	`0x22`
`\a`	Bell	`0x07`
`\b`	Backspace	`0x08`
`\f`	Form feed	`0x0c`
`\n`	Newline	`0x0a`
`\r`	Carriage return	`0x0d`
`\t`	Tab	`0x09`
`\v`	Vertical tab	`0x0b`
`\` *DDD*	Octal value *DDD*	As given
`\x` *XX*	Hexadecimal value *XX*	As given
`\N{`*name*`}`	Unicode character	As given
`\` *o*	Any other character *o*: a two-character string	`0x5c` + as given

A variant of a string literal is a *raw string literal*. The syntax is the same as for quoted or triple-quoted string literals, except that an `r` or `R` immediately precedes the leading quote. In raw string literals, escape sequences are not interpreted as in Table 3-3, but are literally copied into the string, including backslashes and newline characters. Raw string literal syntax is handy for strings that include many backslashes, especially regular expression patterns (see "Pattern String Syntax" on page 306) and Windows absolute filenames (which use backslashes as directory separators). A raw string literal cannot end with an odd number of backslashes: the last one would be taken as escaping the terminating quote.

> **Raw and Triple-Quoted String Literals Are Not Different Types**
>
> Raw and triple-quoted string literals are *not* types different from other strings; they are just alternative syntaxes for literals of the usual two string types, `bytes` and `str`.

In `str` literals, you can use `\u` followed by four hex digits, or `\U` followed by eight hex digits, to denote Unicode characters; you can also include the escape sequences listed in Table 3-3. `str` literals can also include Unicode characters using the escape sequence `\N{`*`name`*`}`, where *`name`* is a standard Unicode name. For example, `\N{Copyright Sign}` indicates a Unicode copyright sign character (©).

Formatted string literals (commonly called *f-strings*) let you inject formatted expressions into your string "literals," which are therefore no longer constant, but rather are subject to evaluation at execution time. The formatting process is described in "String Formatting" on page 287. From a purely syntactic point of view, these new literals can be regarded as just another kind of string literal.

Multiple string literals of any kind—quoted, triple-quoted, raw, bytes, formatted—can be adjacent, with optional whitespace in between (as long as you do not mix strings containing text and bytes). The compiler concatenates such adjacent string literals into a single string object. Writing a long string literal in this way lets you present it readably across multiple physical lines and gives you an opportunity to insert comments about parts of the string. For example:

```
marypop = ('supercali'       # '(' begins logical line,
           'fragilistic'     # indentation is ignored
           'expialidocious') # until closing ')'
```

The string assigned to `marypop` is a single word of 34 characters.

bytes objects

A `bytes` object is an ordered sequence of `int`s from `0` to `255`. `bytes` objects are usually encountered when reading data from or writing data to a binary source (e.g, a file, a socket, or a network resource).

A `bytes` object can be initialized from a list of `int`s or from a string of characters. A `bytes` literal has the same syntax as a `str` literal, prefixed with `'b'`:

```
b'abc'
bytes([97, 98, 99])          # Same as the previous line
rb'\ = solidus'              # A raw bytes literal, containing a '\'
```

To convert a `bytes` object to a `str`, use the `bytes.decode` method. To convert a `str` object to a `bytes` object, use the `str.encode` method, as described in detail in Chapter 9.

bytearray objects

A `bytearray` is a *mutable* ordered sequence of `int`s from `0` to `255`; like a `bytes` object, you can construct it from a sequence of `int`s or characters. In fact, apart from mutability, it is just like a `bytes` object. As they are mutable, `bytearray` objects support methods and operators that modify elements within the array of byte values:

```
ba = bytearray([97, 98, 99])  # Like bytes, can take a sequence of ints
ba[1] = 97                    # Unlike bytes, contents can be modified
print(ba.decode())            # Prints 'aac'
```

Chapter 9 has additional material on creating and working with `bytearray` objects.

Tuples

A *tuple* is an immutable ordered sequence of items. The items of a tuple are arbitrary objects and may be of different types. You can use mutable objects (such as lists) as tuple items, but best practice is generally to avoid doing so.

To denote a tuple, use a series of expressions (the items of the tuple) separated by commas (`,`);[5] if every item is a literal, the whole construct is a *tuple literal*. You may optionally place a redundant comma after the last item. You can group tuple items within parentheses, but the parentheses are necessary only where the commas would otherwise have another meaning (e.g., in function calls), or to denote empty or nested tuples. A tuple with exactly two items is also known as a *pair*. To create a tuple of one item, add a comma to the end of the expression. To denote an empty tuple, use an empty pair of parentheses. Here are some tuple literals, the second of which uses optional parentheses:

```
100, 200, 300       # Tuple with three items
(3.14,)             # Tuple with one item, needs trailing comma
()                  # Empty tuple (parentheses NOT optional)
```

You can also call the built-in type `tuple` to create a tuple. For example:

```
tuple('wow')
```

This builds a tuple equal to that denoted by the tuple literal:

```
('w', 'o', 'w')
```

`tuple()` without arguments creates and returns an empty tuple, like `()`. When *`x`* is iterable, `tuple(`*`x`*`)` returns a tuple whose items are the same as those in *`x`*.

Lists

A *list* is a mutable ordered sequence of items. The items of a list are arbitrary objects and may be of different types. To denote a list, use a series of expressions (the items

5 This syntax is sometimes called a "tuple display."

of the list) separated by commas (`,`), within brackets (`[]`);[6] if every item is a literal, the whole construct is a *list literal*. You may optionally place a redundant comma after the last item. To denote an empty list, use an empty pair of brackets. Here are some examples of list literals:

```
[42, 3.14, 'hello']  # List with three items
[100]                # List with one item
[]                   # Empty list
```

You can also call the built-in type `list` to create a list. For example:

```
list('wow')
```

This builds a list equal to that denoted by the list literal:

```
['w', 'o', 'w']
```

`list()` without arguments creates and returns an empty list, like `[]`. When *`x`* is iterable, `list(`*`x`*`)` returns a list whose items are the same as those in *`x`*.

You can also build lists with list comprehensions, covered in "List comprehensions" on page 88.

Sets

Python has two built-in set types, `set` and `frozenset`, to represent arbitrarily ordered collections of unique items. Items in a set may be of different types, but they must all be *hashable* (see `hash` in Table 8-2). Instances of type `set` are mutable, and thus not hashable; instances of type `frozenset` are immutable and hashable. You can't have a set whose items are sets, but you can have a set (or frozenset) whose items are frozensets. Sets and frozensets are *not* ordered.

To create a set, you can call the built-in type `set` with no argument (this means an empty set) or one argument that is iterable (this means a set whose items are those of the iterable). You can similarly build a frozenset by calling `frozenset`.

Alternatively, to denote a (nonfrozen, nonempty) set, use a series of expressions (the items of the set) separated by commas (`,`) within braces (`{}`);[7] if every item is a literal, the whole assembly is a *set literal*. You may optionally place a redundant comma after the last item. Here are some example sets (two literals, one not):

```
{42, 3.14, 'hello'}  # Literal for a set with three items
{100}                # Literal for a set with one item
set()                # Empty set - no literal for empty set
                     # {} is an empty dict!
```

You can also build nonfrozen sets with set comprehensions, as discussed in "Set comprehensions" on page 90.

6 This syntax is sometimes called a "list display."

7 This syntax is sometimes called a "set display."

Note that two sets or frozensets (or a set and a frozenset) may compare as equal, but since they are unordered, iterating over them can return their contents in differing order.

Dictionaries

A *mapping* is an arbitrary collection of objects indexed by nearly[8] arbitrary values called *keys*. Mappings are mutable and, like sets but unlike sequences, are *not* (necessarily) ordered.

Python provides a single built-in mapping type: the dictionary type `dict`. Library and extension modules provide other mapping types, and you can write others yourself (as discussed in "Mappings" on page 148). Keys in a dictionary may be of different types, but they must be *hashable* (see `hash` in Table 8-2). Values in a dictionary are arbitrary objects and may be of any type. An item in a dictionary is a key/value pair. You can think of a dictionary as an associative array (known in some other languages as a "map," "hash table," or "hash").

To denote a dictionary, you can use a series of colon-separated pairs of expressions (the pairs are the items of the dictionary) separated by commas (`,`) within braces (`{}`);[9] if every expression is a literal, the whole construct is a *dictionary literal*. You may optionally place a redundant comma after the last item. Each item in a dictionary is written as *`key`*`:`*`value`*, where *`key`* is an expression giving the item's key and *`value`* is an expression giving the item's value. If a key's value appears more than once in a dictionary expression, only an arbitrary one of the items with that key is kept in the resulting dictionary object—dictionaries do not support duplicate keys. For example:

```
{1:2, 3:4, 1:5}  # The value of this dictionary is {1:5, 3:4}
```

To denote an empty dictionary, use an empty pair of braces.

Here are some dictionary literals:

```
{'x':42, 'y':3.14, 'z':7}     # Dictionary with three items, str keys
{1:2, 3:4}                    # Dictionary with two items, int keys
{1:'za', 'br':23}             # Dictionary with different key types
{}                            # Empty dictionary
```

You can also call the built-in type `dict` to create a dictionary in a way that, while less concise, can sometimes be more readable. For example, the `dicts` in the preceding snippet can also be written as:

```
dict(x=42, y=3.14, z=7)       # Dictionary with three items, str keys
dict([(1, 2), (3, 4)])        # Dictionary with two items, int keys
```

8 Each specific mapping type may put some constraints on the type of keys it accepts: in particular, dictionaries only accept hashable keys.

9 This syntax is sometimes called a "dictionary display."

```
dict([(1,'za'), ('br',23)])  # Dictionary with different key types
dict()                       # Empty dictionary
```

`dict()` without arguments creates and returns an empty dictionary, like `{}`. When the argument *x* to `dict` is a mapping, `dict` returns a new dictionary object with the same keys and values as *x*. When *x* is iterable, the items in *x* must be pairs, and `dict(x)` returns a dictionary whose items (key/value pairs) are the same as the items in *x*. If a key value appears more than once in *x*, only the *last* item from *x* with that key value is kept in the resulting dictionary.

When you call `dict` in addition to or instead of the positional argument *x*, you may pass *named arguments*, each with the syntax *name=value*, where *name* is an identifier to use as an item's key and *value* is an expression giving the item's value. When you call `dict` and pass both a positional argument and one or more named arguments, if a key appears both in the positional argument and as a named argument, Python associates to that key the named argument's value (i.e., the named argument "wins").

You can unpack a dict's contents into another dict using the `**` operator.

```
d1 = {'a':1, 'x': 0}
d2 = {'c': 2, 'x': 5}
d3 = {**d1, **d2}  # result is {'a':1, 'x': 5, 'c': 2}
```

3.9+ As of Python 3.9, this same operation can be performed using the | operator.

```
d4 = d1 | d2  # same result as d3
```

You can also create a dictionary by calling `dict.fromkeys`. The first argument is an iterable whose items become the keys of the dictionary; the second argument is the value that corresponds to each and every key (all keys initially map to the same value). If you omit the second argument, it defaults to **None**. For example:

```
dict.fromkeys('hello', 2)    # Same as {'h':2, 'e':2, 'l':2, 'o':2}
dict.fromkeys([1, 2, 3])     # Same as {1:None, 2:None, 3:None}
```

You can also build a `dict` using a dictionary comprehension, as discussed in "Dictionary comprehensions" on page 90.

When comparing two `dict`s for equality, they will evaluate as equal if they have the same keys and corresponding values, even if the keys are not in the same order.

None

The built-in **None** denotes a null object. **None** has no methods or other attributes. You can use **None** as a placeholder when you need a reference but you don't care what object you refer to, or when you need to indicate that no object is there. Functions return **None** as their result unless they have specific **return** statements coded to return other values. **None** is hashable and can be used as a `dict` key.

Ellipsis (...)

The `Ellipsis`, written as three periods with no intervening spaces, `...`, is a special object in Python used in numerical applications,[10] or as an alternative to **`None`** when **`None`** is a valid entry. For instance, to initialize a `dict` that may take **`None`** as a legitimate value, you can initialize it with `...` as an indicator of "no value supplied, not even **`None`**." `Ellipsis` is hashable and so can be used as a `dict` key:

```
tally = dict.fromkeys(['A', 'B', None, ...], 0)
```

Callables

In Python, callable types are those whose instances support the function call operation (see "Calling Functions" on page 101). Functions are callable. Python provides numerous built-in functions (see "Built-in Functions" on page 251) and supports user-defined functions (see "Defining Functions: The def Statement" on page 94). Generators are also callable (see "Generators" on page 109).

Types are callable too, as we saw for the `dict`, `list`, `set`, and `tuple` built-in types. (See "Built-in Types" on page 247 for a complete list of built-in types.) As we discuss in "Python Classes" on page 115, **`class`** objects (user-defined types) are also callable. Calling a type usually creates and returns a new instance of that type.

Other callables include *methods*, which are functions bound as class attributes, and instances of classes that supply a special method named `__call__`.

Boolean Values

Any[11] data value in Python can be used as a truth value: true or false. Any nonzero number or nonempty container (e.g., string, tuple, list, set, or dictionary) is true. Zero (`0`, of any numeric type), **`None`**, and empty containers are false. You may see the terms "truthy" and "falsy" used to indicate values that evaluate as either true or false.

> **Beware Using a Float as a Truth Value**
> Be careful about using a floating-point number as a truth value: that's like comparing the number for exact equality with zero, and floating-point numbers should almost never be compared for exact equality.

The built-in type `bool` is a subclass of `int`. The only two values of type `bool` are **`True`** and **`False`**, which have string representations of **`'True'`** and **`'False'`**, but also numerical values of `1` and `0`, respectively. Several built-in functions return `bool` results, as do comparison operators.

10 See "Shape, indexing, and slicing" on page 507.

11 Strictly speaking, *almost* any: NumPy arrays, covered in Chapter 16, are an exception.

You can call `bool(x)` with any[12] *x* as the argument. The result is **True** when *x* is true and **False** when *x* is false. Good Python style is not to use such calls when they are redundant, as they most often are: *always* write `if x:`, *never* any of `if bool(x):`, `if x is True:`, `if x == True:`, or `if bool(x) == True:`. However, you *can* use `bool(x)` to count the number of true items in a sequence. For example:

```
def count_trues(seq):
    return sum(bool(x) for x in seq)
```

In this example, the `bool` call ensures each item of *seq* is counted as `0` (if false) or `1` (if true), so `count_trues` is more general than `sum(seq)` would be.

When we say "*expression* is true" we mean that `bool(expression)` would return **True**. As we mentioned, this is also known as "*expression* being *truthy*" (the other possibility is that "*expression* is *falsy*").

Variables and Other References

A Python program accesses data values through *references*. A reference is a "name" that refers to a value (object). References take the form of variables, attributes, and items. In Python, a variable or other reference has no intrinsic type. The object to which a reference is bound at a given time always has a type, but a given reference may be bound to objects of various types in the course of the program's execution.

Variables

In Python, there are no "declarations." The existence of a variable begins with a statement that *binds* the variable (in other words, sets a name to hold a reference to some object). You can also *unbind* a variable, resetting the name so it no longer holds a reference. Assignment statements are the usual way to bind variables and other references. The **del** statement unbinds a variable reference, although doing so is rare.

Binding a reference that was already bound is also known as *rebinding* it. Whenever we mention binding, we implicitly include rebinding (except where we explicitly exclude it). Rebinding or unbinding a reference has no effect on the object to which the reference was bound, except that an object goes away when nothing refers to it. The cleanup of objects with no references is known as *garbage collection*.

You can name a variable with any identifier except the 30-plus that are reserved as Python's keywords (see "Keywords" on page 37). A variable can be global or local. A *global variable* is an attribute of a module object (see Chapter 7). A *local variable* lives in a function's local namespace (see "Namespaces" on page 105).

12 With exactly the same exception of NumPy arrays.

Object attributes and items

The main distinction between the attributes and items of an object is in the syntax you use to access them. To denote an *attribute* of an object, use a reference to the object, followed by a period (`.`), followed by an identifier known as the *attribute name*. For example, `x.y` refers to one of the attributes of the object bound to name `x`; specifically, that attribute whose name is `'y'`.

To denote an *item* of an object, use a reference to the object, followed by an expression within brackets []. The expression in brackets is known as the item's *index* or *key*, and the object is known as the item's *container*. For example, `x[y]` refers to the item at the key or index bound to name `y`, within the container object bound to name `x`.

Attributes that are callable are also known as *methods*. Python draws no strong distinctions between callable and noncallable attributes, as some other languages do. All general rules about attributes also apply to callable attributes (methods).

Accessing nonexistent references

A common programming error is to access a reference that does not exist. For example, a variable may be unbound, or an attribute name or item index may not be valid for the object to which you apply it. The Python compiler, when it analyzes and compiles source code, diagnoses only syntax errors. Compilation does not diagnose semantic errors, such as trying to access an unbound attribute, item, or variable. Python diagnoses semantic errors only when the errant code executes—that is, *at runtime*. When an operation is a Python semantic error, attempting it raises an exception (see Chapter 6). Accessing a nonexistent variable, attribute, or item—just like any other semantic error—raises an exception.

Assignment Statements

Assignment statements can be plain or augmented. Plain assignment to a variable (e.g., `name = value`) is how you create a new variable or rebind an existing variable to a new value. Plain assignment to an object attribute (e.g., `x.attr = value`) is a request to object `x` to create or rebind the attribute named `'attr'`. Plain assignment to an item in a container (e.g., `x[k] = value`) is a request to container `x` to create or rebind the item with index or key `k`.

Augmented assignment (e.g., `name += value`) cannot, per se, create new references. Augmented assignment can rebind a variable, ask an object to rebind one of its existing attributes or items, or request the target object to modify itself. When you make any kind of request to an object, it is up to the object to decide whether and how to honor the request, and whether to raise an exception.

Plain assignment

A plain assignment statement in the simplest form has the syntax:

```
target = expression
```

The target is known as the lefthand side (LHS), and the expression is the righthand side (RHS). When the assignment executes, Python evaluates the RHS expression, then binds the expression's value to the LHS target. The binding never depends on the type of the value. In particular, Python draws no strong distinction between callable and noncallable objects, as some other languages do, so you can bind functions, methods, types, and other callables to variables, just as you can numbers, strings, lists, and so on. This is part of functions and other callables being *first-class objects*.

Details of the binding do depend on the kind of target. The target in an assignment may be an identifier, an attribute reference, an indexing, or a slicing, where:

An identifier
: Is a variable name. Assigning to an identifier binds the variable with this name.

An attribute reference
: Has the syntax `obj.name`. `obj` is an arbitrary expression, and `name` is an identifier, known as an *attribute name* of the object. Assigning to an attribute reference asks the object `obj` to bind its attribute named `'name'`.

An indexing
: Has the syntax `obj[expr]`. `obj` and `expr` are arbitrary expressions. Assigning to an indexing asks the container `obj` to bind its item indicated by the value of `expr`, also known as the index or key of the item in the container (an *indexing* is an index *applied to* a container).

A slicing
: Has the syntax `obj[start:stop]` or `obj[start:stop:stride]`. `obj`, `start`, `stop`, and `stride` are arbitrary expressions. `start`, `stop`, and `stride` are all optional (i.e., `obj[:stop:]` and `obj[:stop]` are also syntactically correct slicings, each being equivalent to `obj[None:stop:None]`). Assigning to a slicing asks the container `obj` to bind or unbind some of its items. Assigning to a slicing such as `obj[start:stop:stride]` is equivalent to assigning to the indexing `obj[slice(start, stop, stride)]`. See Python's built-in type `slice` in (Table 8-1), whose instances represent slices (a *slicing* is a slice *applied to* a container).

We'll get back to indexing and slicing targets when we discuss operations on lists in "Modifying a list" on page 66, and on dictionaries in "Indexing a Dictionary" on page 71.

When the target of the assignment is an identifier, the assignment statement specifies the binding of a variable. This is *never* disallowed: when you request it, it takes place. In all other cases, the assignment statement denotes a request to an object to bind one or more of its attributes or items. An object may refuse to create or rebind some (or all) attributes or items, raising an exception if you attempt a disallowed creation or rebinding (see also `__setattr__` in Table 4-1 and `__setitem__` in "Container methods" on page 149).

A plain assignment can use multiple targets and equals signs (=). For example:

```
a = b = c = 0
```

binds variables a, b, and c to the same value, 0. Each time the statement executes, the RHS expression evaluates just once, no matter how many targets are in the statement. Each target, left to right, is bound to the one object returned by the expression, just as if several simple assignments executed one after the other.

The target in a plain assignment can list two or more references separated by commas, optionally enclosed in parentheses or brackets. For example:

```
a, b, c = x
```

This statement requires x to be an iterable with exactly three items, and binds a to the first item, b to the second, and c to the third. This kind of assignment is known as an *unpacking assignment*. The RHS expression must be an iterable with exactly as many items as there are references in the target; otherwise, Python raises an exception. Python binds each reference in the target to the corresponding item in the RHS. You can use an unpacking assignment, for example, to swap references:

```
a, b = b, a
```

This assignment statement rebinds name a to what name b was bound to, and vice versa. Exactly one of the multiple targets of an unpacking assignment may be preceded by *. That *starred* target, if present, is bound to a list of all items, if any, that were not assigned to other targets. For example, when x is a list, this:

```
first, *middle, last = x
```

is the same as (but more concise, clearer, more general, and faster than) this:

```
first, middle, last = x[0], x[1:-1], x[-1]
```

Each of these forms requires x to have at least two items. This feature is known as *extended unpacking*.

Augmented assignment

An *augmented assignment* (sometimes called an *in-place assignment*) differs from a plain assignment in that, instead of an equals sign (=) between the target and the expression, it uses an *augmented operator*, which is a binary operator followed by =. The augmented operators are +=, -=, *=, /=, //=, %=, **=, |=, >>=, <<=, &=, ^=, and @=. An augmented assignment can have only one target on the LHS; augmented assignment does not support multiple targets.

In an augmented assignment, like in a plain one, Python first evaluates the RHS expression. Then, when the LHS refers to an object that has a special method for the appropriate *in-place* version of the operator, Python calls the method with the RHS value as its argument (it is up to the method to modify the LHS object appropriately and return the modified object; "Special Methods" on page 141 covers special methods). When the LHS object has no applicable in-place special method, Python uses the corresponding binary operator on the LHS and RHS objects, then rebinds the target to the result. For example, *x* += *y* is like *x* = *x*.`__iadd__`(*y*) when *x* has the special method `__iadd__` for "in-place addition"; otherwise, *x* += *y* is like *x* = *x* + *y*.

Augmented assignment never creates its target reference; the target must already be bound when augmented assignment executes. Augmented assignment can rebind the target reference to a new object, or modify the same object to which the target reference was already bound. Plain assignment, in contrast, can create or rebind the LHS target reference, but it never modifies the object, if any, to which the target reference was previously bound. The distinction between objects and references to objects is crucial here. For example, `x = x + y` never modifies the object to which *x* was originally bound, if any. Rather, it rebinds *x* to refer to a new object. *x* += *y*, in contrast, modifies the object to which the name *x* is bound, when that object has the special method `__iadd__`; otherwise, *x* += *y* rebinds *x* to a new object, just like *x* = *x* + *y*.

del Statements

Despite its name, a **`del`** statement *unbinds references*—it does *not*, per se, *delete* objects. Object deletion may automatically follow, by garbage collection, when no more references to an object exist.

A **`del`** statement consists of the keyword **`del`**, followed by one or more target references separated by commas (`,`). Each target can be a variable, attribute reference, indexing, or slicing, just like for assignment statements, and must be bound at the time **`del`** executes. When a **`del`** target is an identifier, the **`del`** statement means to unbind the variable. If the identifier was bound, unbinding it is never disallowed; when requested, it takes place.

In all other cases, the **`del`** statement specifies a request to an object to unbind one or more of its attributes or items. An object may refuse to unbind some (or all) attributes or items, raising an exception if you attempt a disallowed unbinding (see also `__delattr__` in "General-Purpose Special Methods" on page 142 and `__delitem__` in "Container methods" on page 149). Unbinding a slicing normally has the same effect as assigning an empty sequence to that slicing, but it is up to the container object to implement this equivalence.

Containers are also allowed to have **`del`** cause side effects. For example, assuming **`del`** *C*`[2]` succeeds, when *C* is a dictionary, this makes future references to *C*`[2]` invalid (raising `KeyError`) until and unless you assign to *C*`[2]` again; but when *C* is a list, **`del`** *C*`[2]` implies that every following item of *C* "shifts left by one"—so, if *C* is long enough, future references to *C*`[2]` are still valid, but denote a different item than they did before the **`del`** (generally, what you'd have used *C*`[3]` to refer to, before the **`del`** statement).

Expressions and Operators

An expression is a "phrase" of code, which Python evaluates to produce a value. The simplest expressions are literals and identifiers. You build other expressions by joining subexpressions with the operators and/or delimiters listed in Table 3-4. This table lists operators in decreasing order of precedence, higher precedence before lower. Operators listed together have the same precedence. The third column lists the associativity of the operator: L (left-to-right), R (right-to-left), or NA (nonassociative).

Table 3-4. Operator precedence in expressions

Operator	Description	Associativity
{ *key* : *expr*, ... }	Dictionary creation	NA
{ *expr*, ... }	Set creation	NA
[*expr*, ...]	List creation	NA
(*expr*, ...)	Tuple creation (parentheses recommended, but not always required; at least one comma required), or just parentheses	NA
f (*expr*, ...)	Function call	L
x [*index*: *index*: *step*]	Slicing	L
x [*index*]	Indexing	L
x . *attr*	Attribute reference	L
x ** *y*	Exponentiation (*x* to the *y*th power)	R
~ *x*, + *x*, - *x*	Bitwise NOT, unary plus and minus	NA
x * *y*, *x* @ *y*, *x* / *y*, *x* // *y*, *x* % *y*	Multiplication, matrix multiplication, division, floor division, remainder	L
x + *y*, *x* - *y*	Addition, subtraction	L
x << *y*, *x* >> *y*	Left-shift, right-shift	L
x & *y*	Bitwise AND	L
x ^ *y*	Bitwise XOR	L
x | *y*	Bitwise OR	L
x < *y*, *x* <= *y*, *x* > *y*, *x* >= *y*, *x* != *y*, *x* == *y*	Comparisons (less than, less than or equal, greater than, greater than or equal, inequality, equality)	NA
x **is** *y*, *x* **is not** *y*	Identity tests	NA
x **in** *y*, *x* **not in** *y*	Membership tests	NA
not *x*	Boolean NOT	NA
x **and** *y*	Boolean AND	L
x **or** *y*	Boolean OR	L
x **if** *expr* **else** *y*	Conditional expression (or ternary operator)	NA

Operator	Description	Associativity
lambda *arg*, ...: *expr*	Anonymous simple function	NA
(*ident* := *expr*)	Assignment expression (parentheses recommended, but not always required)	NA

In this table, *expr*, *key*, *f*, *index*, *x*, and *y* mean any expression, while *attr*, *arg*, and *ident* mean any identifier. The notation , ... means commas join zero or more repetitions; in such cases, a trailing comma is optional and innocuous.

Comparison Chaining

You can chain comparisons, implying a logical **and**. For example:

```
a < b <= c < d
```

where *a*, *b*, *c*, and *d* are arbitrary expressions, has (in the absence of evaluation side effects) the same value as:

```
a < b and b <= c and c < d
```

The chained form is more readable, and evaluates each subexpression at most once.

Short-Circuiting Operators

The **and** and **or** operators *short-circuit* their operands' evaluation: the righthand operand evaluates only when its value is needed to get the truth value of the entire **and** or **or** operation.

In other words, *x* **and** *y* first evaluates *x*. When *x* is false, the result is *x*; otherwise, the result is *y*. Similarly, *x* **or** *y* first evaluates *x*. When *x* is true, the result is *x*; otherwise, the result is *y*.

and and **or** don't force their results to be **True** or **False**, but rather return one or the other of their operands. This lets you use these operators more generally, not just in Boolean contexts. **and** and **or**, because of their short-circuiting semantics, differ from other operators, which fully evaluate all operands before performing the operation. **and** and **or** let the left operand act as a *guard* for the right operand.

The conditional operator

Another short-circuiting operator is the conditional[13] operator **if**/**else**:

```
when_true if condition else when_false
```

Each of *when_true*, *when_false*, and *condition* is an arbitrary expression. *condition* evaluates first. When *condition* is true, the result is *when_true*; otherwise, the

13 Sometimes referred to as the *ternary* operator, as it is so called in C (Python's original implementation language).

result is *when_false*. Only one of the subexpressions *when_true* and *when_false* evaluates, depending on the truth value of *condition*.

The order of the subexpressions in this conditional operator may be a bit confusing. The recommended style is to always place parentheses around the whole expression.

Assignment Expressions

3.8+ You can combine evaluation of an expression and the assignment of its result using the `:=` operator. There are several common cases where this is useful.

:= in an if/elif statement

Code that assigns a value and then checks it can be collapsed using `:=`:

```
re_match = re.match(r'Name: (\S)', input_string)
if re_match:
    print(re_match.groups(1))

# collapsed version using :=
if (re_match := re.match(r'Name: (\S)', input_string)):
    print(re_match.groups(1))
```

This is especially helpful when writing a sequence of **`if/elif`** blocks (you'll find a more extended example in Chapter 10).

:= in a while statement

Use `:=` to simplify code that uses a variable as its **`while`** condition. Consider this code that works with a sequence of values returned by some function `get_next_value`, which returns **`None`** when there are no more values to process:

```
current_value = get_next_value()
while current_value is not None:
    if not filter_condition(current_value):
        continue    # BUG! Current_value is not advanced to next
    # ... do some work with current_value ...
    current_value = get_next_value()
```

This code has a couple of problems. First, there is the duplicated call to `get_next_value`, which carries extra maintenance costs when `get_next_value` changes. But more seriously, there is a bug when an early exiting filter is added: the **`continue`** statement jumps directly back to the **`while`** statement without advancing to the next value, creating an infinite loop.

When we use `:=` to incorporate the assignment into the **`while`** statement itself, we fix the duplication problem, and calling **`continue`** does not cause an infinite loop:

```
while (current_value := get_next_value()) is not None:
    if not filter_condition(current_value):
        continue    # no bug, current_value advances in while statement
    # ... do some work with current_value ...
```

:= in a list comprehension filter

A list comprehension that converts an input item but must filter out some items based on their converted values can use `:=` to do the conversion only once. In this example, a function to convert `strs` to `ints` returns **`None`** for invalid values. Without `:=`, the list comprehension must call `safe_int` twice for valid values, once to check for **`None`** and then again to add the actual `int` value to the list:

```
def safe_int(s):
    try:
        return int(s)
    except Exception:
        return None

input_strings = ['1','2','a','11']

valid_int_strings = [safe_int(s) for s in input_strings
                     if safe_int(s) is not None]
```

If we use an assignment expression in the condition part of the list comprehension, `safe_int` only gets called once for each value in `input_strings`:

```
valid_int_strings = [int_s for s in input_strings
                     if (int_s := safe_int(s)) is not None]
```

You can find more examples in the original PEP for this feature, PEP 572.

Numeric Operations

Python offers the usual numeric operations, as we've just seen in Table 3-4. Numbers are immutable objects: when you perform operations on number objects, you always produce new objects and never modify existing ones. You can access the parts of a complex object *z* as read-only attributes `z.real` and `z.imag`. Trying to rebind these attributes raises an exception.

A number's optional `+` or `-` sign, and the `+` or `-` that joins a floating-point literal to an imaginary one to make a complex number, are not part of the literals' syntax. They are ordinary operators, subject to normal operator precedence rules (see Table 3-4). For example, `-2 ** 2` evaluates to `-4`: exponentiation has higher precedence than unary minus, so the whole expression parses as `-(2 ** 2)`, not as `(-2) ** 2`. (Again, parentheses are recommended, to avoid confusing a reader of the code.)

Numeric Conversions

You can perform arithmetic operations and comparisons between any two numbers of Python built-in types (integers, floating-point numbers, and complex numbers). If the operands' types differ, Python converts the operand with the "narrower" type to the "wider" type.[14] The built-in numeric types, in order from narrowest to widest, are `int`, `float`, and `complex`. You can request an explicit conversion by passing a noncomplex numeric argument to any of these types. `int` drops its argument's fractional part, if any (e.g., `int(9.8)` is `9`). You can also call `complex` with two numeric arguments, giving real and imaginary parts. You cannot convert a `complex` to another numeric type in this way, because there is no single unambiguous way to convert a complex number into, for example, a `float`.

You can also call each built-in numeric type with a string argument with the syntax of an appropriate numeric literal, with small extensions: the argument string may have leading and/or trailing whitespace, may start with a sign, and—for complex numbers—may sum or subtract a real part and an imaginary one. `int` can also be called with two arguments: the first one a string to convert, and the second the *radix*, an integer between 2 and 36 to use as the base for the conversion (e.g., `int('101', 2)` returns `5`, the value of `'101'` in base 2). For radices larger than 10, the appropriate subset of ASCII letters from the start of the alphabet (in either lower- or uppercase) are the extra needed "digits."[15]

Arithmetic Operations

Arithmetic operations in Python behave in rather obvious ways, with the possible exception of division and exponentiation.

Division

When the right operand of `/`, `//`, or `%` is `0`, Python raises an exception at runtime. Otherwise, the `/` operator performs *true* division, returning the floating-point result of division of the two operands (or a complex result if either operand is a complex number). In contrast, the `//` operator performs *floor* division, which means it returns an integer result (converted to the same type as the wider operand) that's the largest integer less than or equal to the true division result (ignoring the remainder, if any); e.g., `5.0 // 2 = 2.0` (not `2`). The `%` operator returns the remainder of the (floor) division, i.e., the integer such that `(x // y) * y + (x % y) == x`.

–x // y Is Not the Same as int(–x / y)

Take care not to think of `//` as a truncating or integer form of division; this is only the case for operands of the same sign. When operands are of different signs, the largest integer less than or equal to the true division result will actually be a more negative value than the result from true division (for example, `-5 / 2` returns `-2.5`, so `-5 // 2` returns `-3`, not `-2`).

14 This is not, strictly speaking, the "coercion" you observe in other languages; however, among built-in numeric types, it produces pretty much the same effect.

15 Hence the upper limit of 36 for the radix: 10 numeric digits plus 26 alphabetic characters.

The built-in `divmod` function takes two numeric arguments and returns a pair whose items are the quotient and remainder, so you don't have to use both `//` for the quotient and `%` for the remainder.[16]

Exponentiation

The exponentiation ("raise to power") operation, when *a* is less than zero and *b* is a floating-point value with a nonzero fractional part, returns a complex number. The built-in `pow(a, b)` function returns the same result as `a ** b`. With three arguments, `pow(a, b, c)` returns the same result as `(a ** b) % c` but may sometimes be faster. Note that, unlike other arithmetic operations, exponentiation evaluates right to left: in other words, `a ** b ** c` evaluates as `a ** (b ** c)`.

Comparisons

All objects, including numbers, can be compared for equality (`==`) and inequality (`!=`). Comparisons requiring order (`<`, `<=`, `>`, `>=`) may be used between any two numbers unless either operand is complex, in which case they raise exceptions at runtime. All these operators return Boolean values (**`True`** or **`False`**). Be careful when comparing floating-point numbers for equality, however, as discussed in Chapter 16 and the online tutorial on floating-point arithmetic.

Bitwise Operations on Integers

`int`s can be interpreted as strings of bits and used with the bitwise operations shown in Table 3-4. Bitwise operators have lower priority than arithmetic operators. Positive `int`s are conceptually extended by an unbounded string of bits on the left, each bit being `0`. Negative `int`s, as they're held in two's complement representation, are conceptually extended by an unbounded string of bits on the left, each bit being `1`.

Sequence Operations

Python supports a variety of operations applicable to all sequences, including strings, lists, and tuples. Some sequence operations apply to all containers (including sets and dictionaries, which are not sequences); some apply to all iterables (meaning "any object over which you can loop"—all containers, be they sequences or not, are iterable, and so are many objects that are not containers, such as files, covered in "The io Module" on page 322, and generators, covered in "Generators"

16 The second item of `divmod`'s result, just like the result of `%`, is the *remainder*, not the *modulo*, despite the function's misleading name. The difference matters when the divisor is negative. In some other languages, such as C# and JavaScript, the result of a `%` operator is, in fact, the modulo; in others yet, such as C and C++, it is machine-dependent whether the result is the modulo or the remainder when either operand is negative. In Python, it's the remainder.

on page 109). In the following we use the terms *sequence*, *container*, and *iterable* quite precisely, to indicate exactly which operations apply to each category.

Sequences in General

Sequences are ordered containers with items that are accessible by indexing and slicing.

The built-in `len` function takes any container as an argument and returns the number of items in the container.

The built-in `min` and `max` functions take one argument, an iterable whose items are comparable, and return the smallest and largest items, respectively. You can also call `min` and `max` with multiple arguments, in which case they return the smallest and largest arguments, respectively.

`min` and `max` also accept two keyword-only optional arguments: `key`, a callable to apply to each item (the comparisons are then performed on the callable's results rather than on the items themselves); and `default`, the value to return when the iterable is empty (when the iterable is empty and you supply no default argument, the function raises `ValueError`). For example, `max('who', 'why', 'what', key=len)` returns `'what'`.

The built-in `sum` function takes one argument, an iterable whose items are numbers, and returns the sum of the numbers.

Sequence conversions

There is no implicit conversion between different sequence types. You can call the built-ins `tuple` and `list` with a single argument (any iterable) to get a new instance of the type you're calling, with the same items, in the same order, as in the argument.

Concatenation and repetition

You can concatenate sequences of the same type with the `+` operator. You can multiply a sequence *S* by an integer *n* with the `*` operator. *S*`*`*n* is the concatenation of *n* copies of *S*. When *n* `<= 0`, *S* `*` *n* is an empty sequence of the same type as *S*.

Membership testing

The *x* **`in`** *S* operator tests to check whether the object *x* equals any item in the sequence (or other kind of container or iterable) *S*. It returns **`True`** when it does and **`False`** when it doesn't. The *x* **`not in`** *S* operator is equivalent to **`not`** `(`*x* **`in`** *S*`)`. For dictionaries, *x* **`in`** *S* tests for the presence of *x* as a key. In the specific case of strings, *x* **`in`** *S* may match more than expected; in this case, *x* **`in`** *S* tests whether *x* equals any *substring* of *S*, not just any single character.

Indexing a sequence

To denote the *n*th item of a sequence *S*, use indexing: `S[n]`. Indexing is zero-based: *S*'s first item is `S[0]`. If *S* has *L* items, the index *n* may be `0`, `1`… up to and including `L-1`, but no larger. *n* may also be `-1`, `-2`… down to and including `-L`, but no smaller. A negative *n* (e.g., `-1`) denotes the same item in *S* as *L*+*n* (e.g., `L-1`) does. In other words, `S[-1]`, like `S[L-1]`, is the last element of *S*, `S[-2]` is the next-to-last one, and so on. For example:

```
x = [10, 20, 30, 40]
x[1]                  # 20
x[-1]                 # 40
```

Using an index `>=L` or `<-L` raises an exception. Assigning to an item with an invalid index also raises an exception. You can add elements to a list, but to do so you assign to a slice, not to an item, as we'll discuss shortly.

Slicing a sequence

To indicate a subsequence of *S*, you can use slicing, with the syntax `S[i:j]`, where *i* and *j* are integers. `S[i:j]` is the subsequence of *S* from the *i*th item, included, to the *j*th item, excluded (in Python, ranges always include the lower bound and exclude the upper bound). A slice is an empty subsequence when *j* is less than or equal to *i*, or when *i* is greater than or equal to *L*, the length of *S*. You can omit *i* when it is equal to `0`, so that the slice begins from the start of *S*. You can omit *j* when it is greater than or equal to *L*, so that the slice extends all the way to the end of *S*. You can even omit both indices, to mean a shallow copy of the entire sequence: `S[:]`. Either or both indices may be less than zero. Here are some examples:

```
x = [10, 20, 30, 40]
x[1:3]                  # [20, 30]
x[1:]                   # [20, 30, 40]
x[:2]                   # [10, 20]
```

A negative index *n* in slicing indicates the same spot in *S* as *L*+*n*, just like it does in indexing. An index greater than or equal to *L* means the end of *S*, while a negative index less than or equal to `-L` means the start of *S*.

Slicing can use the extended syntax `S[i:j:k]`. *k* is the *stride* of the slice, meaning the distance between successive indices. `S[i:j]` is equivalent to `S[i:j:1]`, `S[::2]` is the subsequence of *S* that includes all items that have an even index in *S*, and `S[::-1]` is a slicing, also whimsically known as "the Martian smiley," with the same items as *S* but in reverse order. With a negative stride, in order to have a nonempty slice, the second ("stop") index needs to be *smaller* than the first ("start") one—the reverse of the condition that must hold when the stride is positive. A stride of `0` raises an exception. Here are some examples:

```
>>> y = list(range(10))  # values from 0-9
>>> y[-5:]               # last five items
[5, 6, 7, 8, 9]
>>> y[::2]               # every other item
[0, 2, 4, 6, 8]
>>> y[10:0:-2]           # every other item, in reverse order
[9, 7, 5, 3, 1]
>>> y[:0:-2]             # every other item, in reverse order (simpler)
[9, 7, 5, 3, 1]
>>> y[::-2]              # every other item, in reverse order (best)
[9, 7, 5, 3, 1]
```

Strings

String objects (both `str` and `bytes`) are immutable: attempting to rebind or delete an item or slice of a string raises an exception. (Python also has a built-in type that is mutable but otherwise equivalent to `bytes`: `bytearray` (see "bytearray objects" on page 47). The items of a text string (each of the characters in the string) are themselves text strings, each of length 1—Python has no special data type for "single characters" (the items of a `bytes` or `bytearray` object are `int`s). All slices of a string are strings of the same kind. String objects have many methods, covered in "Methods of String Objects" on page 281.

Tuples

Tuple objects are immutable: therefore, attempting to rebind or delete an item or slice of a tuple raises an exception. The items of a tuple are arbitrary objects and may be of different types; tuple items may be mutable, but we recommend not mutating them, as doing so can be confusing. The slices of a tuple are also tuples. Tuples have no normal (nonspecial) methods, except `count` and `index`, with the same meanings as for lists; they do have many of the special methods covered in "Special Methods" on page 141.

Lists

List objects are mutable: you may rebind or delete items and slices of a list. Items of a list are arbitrary objects and may be of different types. Slices of a list are lists.

Modifying a list

You can modify (rebind) a single item in a list by assigning to an indexing. For instance:

```
x = [1, 2, 3, 4]
x[1] = 42                # x is now [1, 42, 3, 4]
```

Another way to modify a list object *L* is to use a slice of *L* as the target (LHS) of an assignment statement. The RHS of the assignment must be an iterable. When the LHS slice is in extended form (i.e., the slicing specifies a stride other than `1`), then the RHS must have just as many items as the number of items in the LHS slice. When the LHS slicing does not specify a stride, or explicitly specifies a stride of `1`, the LHS slice and the RHS may each be of any length; assigning to such a slice of a list can make the list longer or shorter. For example:

```
x = [10, 20, 30, 40, 50]
# replace items 1 and 2
x[1:3] = [22, 33, 44]    # x is now [10, 22, 33, 44, 40, 50]
# replace items 1-3
x[1:4] = [88, 99]        # x is now [10, 88, 99, 40, 50]
```

There are some important special cases of assignment to slices:

- Using the empty list `[]` as the RHS expression removes the target slice from *L*. In other words, `L[i:j] = []` has the same effect as `del L[i:j]` (or the peculiar statement `L[i:j] *= 0`).
- Using an empty slice of *L* as the LHS target inserts the items of the RHS at the appropriate spot in *L*. For example, `L[i:i] = ['a', 'b']` inserts `'a'` and `'b'` before the item that was at index *i* in *L* prior to the assignment.
- Using a slice that covers the entire list object, `L[:]`, as the LHS target totally replaces the contents of *L*.

You can delete an item or a slice from a list with **`del`**. For instance:

```
x = [1, 2, 3, 4, 5]
del x[1]                 # x is now [1, 3, 4, 5]
del x[::2]               # x is now [3, 5]
```

In-place operations on a list

List objects define in-place versions of the `+` and `*` operators, which you can use via augmented assignment statements. The augmented assignment statement `L += L1` has the effect of adding the items of the iterable *L1* to the end of *L*, just like

L.extend(*L1*). *L* *= *n* has the effect of adding *n*-1 copies of *L* to the end of *L*; if *n* <= 0, *L* *= *n* makes *L* empty, like *L*[:] = [] or **del** *L*[:].

List methods

List objects provide several methods, as shown in Table 3-5. Nonmutating methods return a result without altering the object to which they apply, while mutating methods may alter the object to which they apply. Many of a list's mutating methods behave like assignments to appropriate slices of the list. In this table, *L* indicates any list object, *i* any valid index in *L*, *s* any iterable, and *x* any object.

Table 3-5. List object methods

Nonmutating	
count	*L*.count(*x*) Returns the number of items of *L* that are equal to *x*.
index	*L*.index(*x*) Returns the index of the first occurrence of an item in *L* that is equal to *x*, or raises an exception if *L* has no such item.
Mutating	
append	*L*.append(*x*) Appends item *x* to the end of *L* ; like *L*[len(*L*):] = [x].
clear	*L*.clear() Removes all items from *L*, leaving *L* empty.
extend	*L*.extend(*s*) Appends all the items of iterable *s* to the end of *L*; like *L*[len(*L*):] = *s* or *L* += *s*.
insert	*L*.insert(*i*, *x*) Inserts item *x* in *L* before the item at index *i*, moving following items of *L* (if any) "rightward" to make space (increases len(*L*) by one, does not replace any item, does not raise exceptions; acts just like *L*[*i*:*i*]=[*x*]).
pop	*L*.pop(*i*=-1) Returns the value of the item at index *i* and removes it from *L*; when you omit *i*, removes and returns the last item; raises an exception when *L* is empty or *i* is an invalid index in *L*.
remove	*L*.remove(*x*) Removes from *L* the first occurrence of an item in *L* that is equal to *x*, or raises an exception when *L* has no such item.
reverse	*L*.reverse() Reverses, in place, the items of *L*.
sort	*L*.sort(key=**None**, reverse=**False**) Sorts, in place, the items of *L* (in ascending order, by default; in descending order, if the argument reverse is **True**). When the argument key is not **None**, what gets compared for each item *x* is key(*x*), not *x* itself. For more details, see the following section.

All mutating methods of list objects, except pop, return **None**.

Sorting a list

A list's `sort` method causes the list to be sorted in place (reordering items to place them in increasing order) in a way that is guaranteed to be stable (elements that compare equal are not exchanged). In practice, `sort` is extremely fast—often *preternaturally* fast, as it can exploit any order or reverse order that may be present in any sublist (the advanced algorithm `sort` uses, known as *timsort*[17] to honor its inventor, great Pythonista Tim Peters, is a "non-recursive adaptive stable natural mergesort/binary insertion sort hybrid"—now *there's* a mouthful for you!).

The `sort` method takes two optional arguments, which may be passed with either positional or named-argument syntax. The argument `key`, if not **`None`**, must be a function that can be called with any list item as its only argument. In this case, to compare any two items *x* and *y*, Python compares `key(`*x*`)` and `key(`*y*`)` rather than *x* and *y* (internally, Python implements this in the same way as the decorate–sort–undecorate idiom presented in "Searching and sorting" on page 556, but it's much faster). The argument `reverse`, if **`True`**, causes the result of each comparison to be reversed; this is not exactly the same thing as reversing *L* after sorting, because the sort is stable (elements that compare equal are never exchanged) whether the argument `reverse` is **`True`** or **`False`**. In other words, Python sorts the list in ascending order by default, or in descending order if `reverse` is **`True`**:

```
mylist = ['alpha', 'Beta', 'GAMMA']
mylist.sort()                  # ['Beta', 'GAMMA', 'alpha']
mylist.sort(key=str.lower)     # ['alpha', 'Beta', 'GAMMA']
```

Python also provides the built-in function `sorted` (covered in Table 8-2) to produce a sorted list from any input iterable. `sorted`, after the first argument (which is the iterable supplying the items), accepts the same two optional arguments as a list's `sort` method.

The standard library module `operator` (covered in "The operator Module" on page 493) supplies higher-order functions `attrgetter`, `itemgetter`, and `methodcaller`, which produce functions particularly suitable for the optional `key` argument of the list's `sort` method and the built-in function `sorted`. This optional argument also exists, with exactly the same meaning, for the built-in functions `min` and `max`, as well as for the functions `nsmallest`, `nlargest`, and `merge` in the standard library module `heapq` (covered in "The heapq Module" on page 271) and the class `groupby` in the standard library module `itertools` (covered in "The itertools Module" on page 275).

17 Timsort has the distinction of being the only sorting algorithm mentioned by the US Supreme Court, specifically in the case of Oracle v. Google.

Set Operations

Python provides a variety of operations applicable to sets (both plain and frozen). Since sets are containers, the built-in `len` function can take a set as its single argument and return the number of items in the set. A set is iterable, so you can pass it to any function or method that takes an iterable argument. In this case, iteration yields the items of the set in some arbitrary order. For example, for any set *S*, `min(`*S*`)` returns the smallest item in *S*, since `min` with a single argument iterates on that argument (the order does not matter, because the implied comparisons are transitive).

Set Membership

The *k* **`in`** *S* operator checks whether the object *k* equals one of the items in the set *S*. It returns **`True`** when the set contains *k*, and **`False`** when it doesn't. *k* **`not in`** *S* is like **`not`** (*k* **`in`** *S*).

Set Methods

Set objects provide several methods, as shown in Table 3-6. Nonmutating methods return a result without altering the object to which they apply, and can also be called on instances of `frozenset`; mutating methods may alter the object to which they apply, and can be called only on instances of `set`. In this table, *s* denotes any set object, *s1* any iterable with hashable items (often but not necessarily a `set` or `frozenset`), and *x* any hashable object.

Table 3-6. Set object methods

Nonmutating	
`copy`	*s*`.copy()` Returns a shallow copy of *s* (a copy whose items are the same objects as *s*'s, not copies thereof); like `set(`*s*`)`
`difference`	*s*`.difference(`*s1*`)` Returns the set of all items of *s* that aren't in *s1*; can be written as *s* `-` *s1*
`intersection`	*s*`.intersection(`*s1*`)` Returns the set of all items of *s* that are also in *s1*; can be written as *s* & *s1*
`isdisjoint`	*s*`.isdisjoint(`*s1*`)` Returns **`True`** if the intersection of *s* and *s1* is the empty set (they have no items in common), and otherwise returns **`False`**
`issubset`	*s*`.issubset(`*s1*`)` Returns **`True`** when all items of *s* are also in *s1*, and otherwise returns **`False`**; can be written as *s* <= *s1*
`issuperset`	*s*`.issuperset(`*s1*`)` Returns **`True`** when all items of *s1* are also in *s*, and otherwise returns **`False`** (like *s1*`.issubset(`*s*`)`); can be written as *s* >= *s1*

symmetric_difference	*s*.symmetric_difference(*s1*) Returns the set of all items that are in either *s* or *s1*, but not both; can be written *s* ^ *s1*
union	*s*.union(*s1*) Returns the set of all items that are in *s*, *s1*, or both; can be written as *s* | *s1*
Mutating	
add	*s*.add(*x*) Adds *x* as an item to *s*; no effect if *x* was already an item in *s*
clear	*s*.clear() Removes all items from *s*, leaving *s* empty
discard	*s*.discard(*x*) Removes *x* as an item of *s*; no effect when *x* was not an item of *s*
pop	*s*.pop() Removes and returns an arbitrary item of *s*
remove	*s*.remove(*x*) Removes *x* as an item of *s*; raises a KeyError exception when *x* was not an item of *s*

All mutating methods of set objects, except pop, return **None**.

The pop method can be used for destructive iteration on a set, consuming little extra memory. The memory savings make pop usable for a loop on a huge set, when what you want is to "consume" the set in the course of the loop. Besides saving memory, a potential advantage of a destructive loop such as this:

```
while S:
    item = S.pop()
    # ...handle item...
```

in comparison to a nondestructive loop such as this:

```
for item in S:
    # ...handle item...
```

is that in the body of the destructive loop you're allowed to modify *S* (adding and/or removing items), which is not allowed in the nondestructive loop.

Sets also have mutating methods named difference_update, intersection_update, symmetric_difference_update, and update (corresponding to the nonmutating method union). Each such mutating method performs the same operation as the corresponding nonmutating method, but it performs the operation in place, altering the set on which you call it, and returns **None**.

The four corresponding nonmutating methods are also accessible with operator syntax (where *S2* is a set or frozenset, respectively, *S* - *S2*, *S* & *S2*, *S* ^ *S2*, and *S* | *S2*) and the mutating methods are accessible with augmented assignment syntax (respectively, *S* -= *S2*, *S* &= *S2*, *S* ^= *S2*, and *S* |= *S2*). In addition, sets and frozensets also support comparison operators: == (the sets have the same items;

that is, they're "equal" sets), `!=` (the reverse of `==`), `>=` (`issuperset`), `<=` (`issubset`), `<` (`issubset` and not equal), and `>` (`issuperset` and not equal).

When you use operator or augmented assignment syntax, both operands must be `set`s or `frozenset`s; however, when you call named methods, argument *S1* can be any iterable with hashable items, and it works just as if the argument you passed was `set(S1)`.

Dictionary Operations

Python provides a variety of operations applicable to dictionaries. Since dictionaries are containers, the built-in `len` function can take a dictionary as its argument and return the number of items (key/value pairs) in the dictionary. A dictionary is iterable, so you can pass it to any function that takes an iterable argument. In this case, iteration yields only the keys of the dictionary, in insertion order. For example, for any dictionary *D*, `min(D)` returns the smallest key in *D* (the order of keys in the iteration doesn't matter here).

The Python Language

Dictionary Membership

The *k* **`in`** *D* operator checks whether the object *k* is a key in the dictionary *D*. It returns **`True`** if the key is present, and **`False`** otherwise. *k* **`not in`** *D* is like **`not`** (*k* **`in`** *D*).

Indexing a Dictionary

To denote the value in a dictionary *D* currently associated with the key *k*, use an indexing: `D[k]`. Indexing with a key that is not present in the dictionary raises an exception. For example:

```
d = {'x':42, 'h':3.14, 'z':7}
d['x']                        # 42
d['z']                        # 7
d['a']                        # raises KeyError exception
```

Plain assignment to a dictionary indexed with a key that is not yet in the dictionary (e.g., `D[newkey]=value`) is a valid operation and adds the key and value as a new item in the dictionary. For instance:

```
d = {'x':42, 'h':3.14}
d['a'] = 16                   # d is now {'x':42, 'h':3.14, 'a':16}
```

The **`del`** statement, in the form **`del`** `D[k]`, removes from the dictionary the item whose key is *k*. When *k* is not a key in dictionary *D*, **`del`** `D[k]` raises a `KeyError` exception.

Dictionary Methods

Dictionary objects provide several methods, as shown in Table 3-7. Nonmutating methods return a result without altering the object to which they apply, while mutating methods may alter the object to which they apply. In this table, *d* and *d1* indicate any dictionary objects, *k* any hashable object, and *x* any object.

Table 3-7. Dictionary object methods

Nonmutating	
`copy`	`d.copy()` Returns a shallow copy of the dictionary (a copy whose items are the same objects as *D*'s, not copies thereof, just like `dict(d)`)
`get`	`d.get(k[, x])` Returns `d[k]` when *k* is a key in *d*; otherwise, returns *x* (or **None**, when you don't pass *x*)
`items`	`d.items()` Returns an iterable view object whose items are all current items (key/value pairs) in *d*
`keys`	`d.keys()` Returns an iterable view object whose items are all current keys in *d*
`values`	`d.values()` Returns an iterable view object whose items are all current values in *d*
Mutating	
`clear`	`d.clear()` Removes all items from *d*, leaving *d* empty
`pop`	`d.pop(k[, x])` Removes and returns `d[k]` when *k* is a key in *d*; otherwise, returns *x* (or raises a `KeyError` exception when you don't pass *x*)
`popitem`	`d.popitem()` Removes and returns the items from *d* in last-in, first-out order
`setdefault`	`d.setdefault(k, x)` Returns `d[k]` when *k* is a key in *d*; otherwise, sets `d[k]` equal to *x* (or **None**, when you don't pass *x*), then returns `d[k]`
`update`	`d.update(d1)` For each *k* in mapping *d1*, sets `d[k]` equal to `d1[k]`

The `items`, `keys`, and `values` methods return values known as *view objects*. If the underlying `dict` changes, the retrieved view also changes; Python doesn't allow you to alter the set of keys in the underlying `dict` while using a **`for`** loop on any of its view objects.

Iterating on any of the view objects yields values in insertion order. In particular, when you call more than one of these methods without any intervening change to the `dict`, the order of the results is the same for all of them.

Dictionaries also support the class method `fromkeys(seq, value)`, which returns a dictionary containing all the keys of the given iterable *seq*, each identically initialized with *value*.

Never Modify a dict's Keys While Iterating on It

Don't ever modify the set of keys in a `dict` (i.e., add or remove keys) while iterating over that `dict` or any of the iterable views returned by its methods. If you need to avoid such constraints against mutation during iteration, iterate instead on a list explicitly built from the `dict` or view (i.e., on list(*D*)). Iterating directly on a dict *`D`* is exactly like iterating on *`D`*`.keys()`.

The return values of the `items` and `keys` methods also implement set nonmutating methods and behave much like `frozenset`s; the return value of the method `values` doesn't, since, in contrast to the others (and to `set`s), it may contain duplicates.

The `popitem` method can be used for destructive iteration on a dictionary. Both `items` and `popitem` return dictionary items as key/value pairs. `popitem` is usable for a loop on a huge dictionary, when what you want is to "consume" the dictionary in the course of the loop.

`D``.setdefault(`*`k`*`, `*`x`*`)` returns the same result as *`D`*`.get(`*`k`*`, `*`x`*`)`; but, when *`k`* is not a key in *`D`*, `setdefault` also has the side effect of binding *`D`*`[`*`k`*`]` to the value *`x`*. (In modern Python, `setdefault` is not often used, since the type `collections.defaultdict`, covered in "defaultdict" on page 267, often offers similar, faster, clearer functionality.)

The `pop` method returns the same result as `get`, but when *`k`* is a key in *`D`*, `pop` also has the side effect of removing *`D`*`[`*`k`*`]` (when *`x`* is not specified, and *`k`* is not a key in *`D`*, `get` returns **`None`**, but `pop` raises an exception). *`d`*`.pop(`*`key`*`, `**`None`**`)` is a useful shortcut for removing a key from a `dict` without having to first check if the key is present, much like *`s`*`.discard(`*`x`*`)` (as opposed to *`s`*`.remove(`*`x`*`)`) when *`s`* is a set.

3.9+ The `update` method is accessible with augmented assignment syntax: where *`D2`* is a `dict`, *`D`* `|=` *`D2`* is the same as *`D`*`.update(`*`D2`*`)`. Operator syntax, *`D`* `|` *`D2`*, mutates neither dictionary: rather, it returns a new dictionary result, such that *`D3`* `=` *`D`* `|` *`D2`* is equivalent to *`D3`* `=` *`D`*`.copy();` *`D3`*`.update(`*`D2`*`)`.

The `update` method (but not the `|` and `|=` operators) can also accept an iterable of key/value pairs as an alternative argument instead of a mapping, and can accept named arguments instead of—or in addition to—its positional argument; the semantics are the same as for passing such arguments when calling the built-in `dict` type, as covered in "Dictionaries" on page 49.

Control Flow Statements

A program's *control flow* regulates the order in which the program's code executes. The control flow of a Python program mostly depends on conditional statements, loops, and function calls. (This section covers the **`if`** and **`match`** conditional statements, and **`for`** and **`while`** loops; we cover functions in the following section.) Raising and handling exceptions also affects control flow (via the **`try`** and **`with`** statements); we cover exceptions in Chapter 6.

The if Statement

Often, you'll need to execute some statements only when some condition holds, or choose statements to execute depending on mutually exclusive conditions. The compound statement **if**—comprising **if**, **elif**, and **else** clauses—lets you conditionally execute blocks of statements. The syntax for the **if** statement is:

```
if expression:
    statement(s)
elif expression:
    statement(s)
elif expression:
    statement(s)
...
else:
    statement(s)
```

The **elif** and **else** clauses are optional. Before the introduction of the **match** construct, which we'll look at next, using **if**, **elif**, and **else** was the most common approach for all conditional processing (although at times a `dict` with callables as values might provide a good alternative).

Here's a typical **if** statement with all three kinds of clauses:

```
if x < 0:
    print('x is negative')
elif x % 2:
    print('x is positive and odd')
else:
    print('x is even and nonnegative')
```

Each clause controls one or more statements (known as a block): place the block's statements on separate logical lines after the line containing the clause's keyword (known as the *header line* of the clause), indented four spaces past the header line. The block terminates when the indentation returns to the level of the clause header, or further left from there (this is the style mandated by PEP 8).

You can use any Python expression[18] as the condition in an **if** or **elif** clause. Using an expression this way is known as using it *in a Boolean context*. In this context, any value is taken as being either true or false. As mentioned earlier, any nonzero number or nonempty container (string, tuple, list, dictionary, set, etc.) evaluates as true, while zero (`0`, of any numeric type), **None**, and empty containers evaluate as false. To test a value *x* in a Boolean context, use the following coding style:

```
if x:
```

This is the clearest and most Pythonic form.

18 Except, as already noted, a NumPy array with more than one element.

Do *not* use any of the following:

```
if x is True:
if x == True:
if bool(x):
```

There is a crucial difference between saying that an expression *returns* **True** (meaning the expression returns the value 1 with the bool type) and saying that an expression *evaluates as* true (meaning the expression returns any result that is true in a Boolean context). When testing an expression, for example in an **if** clause, you only care about what it *evaluates as*, not what, precisely, it *returns*. As we previously mentioned, "evaluates as true" is often expressed informally as "is truthy," and "evaluated as false" as "is falsy."

When the **if** clause's condition evaluates as true, the statements within the **if** clause execute, then the entire **if** statement ends. Otherwise, Python evaluates each **elif** clause's condition, in order. The statements within the first **elif** clause whose condition evaluates as true, if any, execute, and the entire **if** statement ends. Otherwise, when an **else** clause exists, it executes. In any case, statements following the entire **if** construct, at the same level, execute next.

The match Statement

3.10+ The **match** statement brings *structural pattern matching* to the Python language. You might think of this as doing for other Python types something similar to what the re module (see "Regular Expressions and the re Module" on page 305) does for strings: it allows easy testing of the structure and contents of Python objects.[19] Resist the temptation to use **match** unless there is a need to analyze the *structure* of an object.

The overall syntactic structure of the statement is the new (soft) keyword **match** followed by an expression whose value becomes the *matching subject*. This is followed by one or more indented **case** clauses, each of which controls the execution of the indented code block it contains:

```
match expression:
    case pattern [if guard]:
        statement(s)
    # ...
```

In execution, Python first evaluates the *expression*, then tests the resulting subject value against the *pattern* in each **case** in turn, in order from first to last, until one matches: then, the block indented within the matching **case** clause evaluates. A pattern can do two things:

19 It is notable that the **match** statement specifically excludes matching values of type str, bytes, and bytearray with *sequence* patterns.

- Verify that the subject is an object with a particular structure.
- Bind matched components to names for further use (usually within the associated **`case`** clause).

When a pattern matches the subject, the *guard* allows a final check before selection of the case for execution. All the pattern's name bindings have occurred, and you can use them in the guard. When there is no guard, or when the guard evaluates as true, the case's indented code block executes, after which the **`match`** statement's execution is complete and no further cases are checked.

The **`match`** statement, per se, provides no default action. If one is needed, the last **`case`** clause must specify a *wildcard* pattern—one whose syntax ensures it matches any subject value. It is a `SyntaxError` to follow a **`case`** clause having such a wildcard pattern with any further **`case`** clauses.

Pattern elements cannot be created in advance, bound to variables, and (for example) reused in multiple places. Pattern syntax is only valid immediately following the (soft) keyword **`case`**, so there is no way to perform such an assignment. For each execution of a **`match`** statement, the interpreter is free to cache pattern expressions that repeat inside the cases, but the cache starts empty for each new execution.

We'll first describe the various types of pattern expressions, before discussing guards and providing some more complex examples.

Pattern Expressions Have Their Own Semantics

The syntax of pattern expressions might seem familiar, but their *interpretation* is sometimes quite different from that of nonpattern expressions, which could mislead readers unaware of those differences. Specific syntactic forms are used in the **`case`** clause to indicate matching of particular structures. A complete summary of this syntax would require more than the simplified notation we use in this book;[20] we therefore prefer to explain this new feature in plain language, with examples. For more detailed examples, refer to the Python documentation.

Building patterns

Patterns are expressions, though with a syntax specific to the **`case`** clause, so familiar grammatical rules apply even though certain features are interpreted differently. They can be enclosed in parentheses to let elements of a pattern be treated as a single expression unit. Like other expressions, patterns have a recursive syntax and can be combined to form more complex patterns. Let's start with the simplest patterns first.

20 Indeed, the syntax notation used in the Python online documentation required, and got, updates to concisely describe some of Python's more recent syntax additions.

Literal patterns

Most literal values are valid patterns. Integer, float, complex number, and string literals (but *not* formatted string literals) are all permissible,[21] and all succeed in matching subjects of the same type and value:

```
>>> for subject in (42, 42.0, 42.1, 1+1j, b'abc', 'abc'):
...     print(subject, end=': ')
...     match subject:
...         case 42: print('integer')  # note this matches 42.0, too!
...         case 42.1: print('float')
...         case 1+1j: print('complex')
...         case b'abc': print('bytestring')
...         case 'abc': print('string')

42: integer
42.0: integer
42.1: float
(1+1j): complex
b'abc': bytestring
abc: string
```

For most matches, the interpreter checks for equality without type checking, which is why `42.0` matches integer `42`. If the distinction is important, consider using class matching (see "Class patterns" on page 81) rather than literal matching. **`True`**, **`False`**, and **`None`** being singleton objects, each matches itself.

The wildcard pattern

In pattern syntax, the underscore (_) plays the role of a wildcard expression. As the simplest wildcard pattern, _ matches any value at all:

```
>>> for subject in 42, 'string', ('tu', 'ple'), ['list'], object:
...     match subject:
...         case _: print('matched', subject)
...

matched 42
matched string
matched ('tu', 'ple')
matched ['list']
matched <class 'object'>
```

Capture patterns

The use of unqualified names (names with no dots in them) is so different in patterns that we feel it necessary to begin this section with a warning.

21 Although comparing `float` or `complex` numbers for exact equality is often dubious practice.

Simple Names Bind to Matched Elements Inside Patterns

Unqualified names—simple identifiers (e.g., *color*) rather than attribute references (e.g., *name.attr*)—do not necessarily have their usual meaning in pattern expressions. Some names, rather than being references to values, are instead bound to elements of the subject value during pattern matching.

Unqualified names, except _, are *capture patterns*. They're wildcards, matching anything, but with a side effect: the name, in the current local namespace, gets bound to the object matched by the pattern. Bindings created by matching remain after the statement has executed, allowing the statements in the **case** clause and subsequent code to process extracted portions of the subject value.

The following example is similar to the preceding one, except that the name x, instead of the underscore, matches the subject. The absence of exceptions shows that the name captures the whole subject in each case:

```
>>> for subject in 42, 'string', ('tu', 'ple'), ['list'], object:
...     match subject:
...         case x: assert x == subject
...
```

Value patterns

This section, too, begins with a reminder to readers that simple names can't be used to inject their bindings into pattern values to be matched.

Represent Variable Values in Patterns with Qualified Names

Because simple names capture values during pattern matching, you *must* use attribute references (qualified names like *name.attr*) to express values that may change between different executions of the same **match** statement.

Though this feature is useful, it means you can't reference values directly with simple names. Therefore, in patterns, values must be represented by qualified names, which are known as *value patterns*—they *represent* values, rather than *capturing* them as simple names do. While slightly inconvenient, to use qualified names you can just set attribute values on an otherwise empty class.[22] For example:

```
>>> class m: v1 = "one"; v2 = 2; v3 = 2.56
...
>>> match ('one', 2, 2.56):
```

22 For this unique use case, it's common to break the normal style conventions about starting class names with an uppercase letter and avoiding using semicolons to stash multiple assignments within one line; however, the authors haven't yet found a style guide that blesses this peculiar, rather new usage.

```
...     case (m.v1, m.v2, m.v3):  print('matched')
...
matched
```

It is easy to give yourself access to the current module's "global" namespace, like this:

```
>>> import sys
>>> g = sys.modules[__name__]
>>> v1 = "one"; v2 = 2; v3 = 2.56
>>> match ('one', 2, 2.56):
...     case (g.v1, g.v2, g.v3):  print('matched')
...
matched
```


OR patterns

When *P1* and *P2* are patterns, the expression *P1 | P2* is an *OR pattern*, matching anything that matches either *P1* or *P2*, as shown in the following example. Any number of alternate patterns can be used, and matches are attempted from left to right:

```
>>> for subject in range(5):
...     match subject:
...         case 1 | 3: print('odd')
...         case 0 | 2 | 4: print('even')
...
even
odd
even
odd
even
```

It is a syntax error to follow a wildcard pattern with further alternatives, however, since they can never be activated. While our initial examples are simple, remember that the syntax is recursive, so patterns of arbitrary complexity can replace any of the subpatterns in these examples.

Group patterns

If *P1* is a pattern, then `(P1)` is also a pattern that matches the same values. This addition of "grouping" parentheses is useful when patterns become complicated, just as it is with standard expressions. Like in other expressions, take care to distinguish between `(P1)`, a simple grouped pattern matching *P1*, and `(P1,)`, a sequence pattern (described next) matching a sequence with a single element matching *P1*.

Sequence patterns

A list or tuple of patterns, optionally with a single starred wildcard (`*_`) or starred capture pattern (`*name`), is a *sequence pattern*. When the starred pattern is absent, the pattern matches a fixed-length sequence of values of the same length as the pattern. Elements of the sequence are matched one at a time, until all elements have matched (then matching succeeds) or an element fails to match (then matching fails).

When the sequence pattern includes a starred pattern, that subpattern matches a sequence of elements sufficiently long to allow the remaining unstarred patterns to match the final elements of the sequence. When the starred pattern is of the form `*name`, `name` is bound to the (possibly empty) list of the elements in the middle that don't correspond to individual patterns at the beginning or end.

You can match a sequence with patterns that look like tuples or lists—it makes no difference to the matching process. The next example shows an unnecessarily complicated way to extract the first, middle, and last elements of a sequence:

```
>>> for sequence in (["one", "two", "three"], range(2), range(6)):
...     match sequence:
...         case  (first, *vars, last): print(first, vars, last)
...

one ['two'] three
0 [] 1
0 [1, 2, 3, 4] 5
```

as patterns

You can use so-called ***as*** *patterns* to capture values matched by more complex patterns, or components of a pattern, that simple capture patterns (see "Capture patterns" on page 77) cannot.

When `P1` is a pattern, then `P1 as name` is also a pattern; when `P1` succeeds, Python binds the matched value to the name `name` in the local namespace. The interpreter tries to ensure that, even with complicated patterns, the same bindings always take place when a match occurs. Therefore, each of the next two examples raises `SyntaxError`, because the constraint cannot be guaranteed:

```
>>> match subject:
...     case ((0 | 1) as x) | 2: print(x)
...

SyntaxError: alternative patterns bind different names
```

```
>>> match subject:
...     case (2 | x): print(x)
...

SyntaxError: alternative patterns bind different names
```

But this one works:

```
>>> match 42:
...     case (1 | 2 | 42) as x: print(x)
...

42
```

Mapping patterns

Mapping patterns match mapping objects, usually dictionaries, that associate keys with values. The syntax of mapping patterns uses *`key`*`:` *`pattern`* pairs. The keys must be either literal or value patterns.

The interpreter iterates over the keys in the mapping pattern, processing each as follows:

- Python looks up the key in the subject mapping; a lookup failure causes an immediate match failure.
- Python then matches the extracted value against the pattern associated with the key; if the value fails to match the pattern, then the whole match fails.

When all keys (and associated values) in the mapping pattern match, the whole match succeeds:

```
>>> match {1: "two", "two": 1}:
...     case {1: v1, "two": v2}: print(v1, v2)
...
two 1
```

You can also use a mapping pattern together with an **as** clause:

```
>>> match {1: "two", "two": 1}:
...     case {1: v1} as v2: print(v1, v2)
...
two {1: 'two', 'two': 1}
```

The **as** pattern in the second example binds *`v2`* to the whole subject dictionary, not just the matched keys.

The final element of the pattern may optionally be a double-starred capture pattern such as `**`*`name`*. When that is the case, Python binds *`name`* to a possibly empty dictionary whose items are the `(`*`key, value`*`)` pairs from the subject mapping whose keys were *not* present in the pattern:

```
>>> match {1: 'one', 2: 'two', 3: 'three'}:
...     case {2: middle, **others}: print(middle, others)
...
two {1: 'one', 3: 'three'}
```

Class patterns

The final and maybe the most versatile kind of pattern is the *class pattern*, offering the ability to match instances of particular classes and their attributes.

A class pattern is of the general form:

```
name_or_attr(patterns)
```

where *name_or_attr* is a simple or qualified name bound to a class—specifically, an instance of the built-in type `type` (or of a subclass thereof, but no super-fancy metaclasses need apply!)—and *patterns* is a (possibly empty) comma-separated list of pattern specifications. When no pattern specifications are present in a class pattern, the match succeeds whenever the subject is an instance of the given class, so for example the pattern `int()` matches *any* integer.

Like function arguments and parameters, the pattern specifications can be positional (like *pattern*) or named (like *name=pattern*). If a class pattern has positional pattern specifications, they must all precede the first named pattern specification. User-defined classes cannot use positional patterns without setting the class's *__match_args__* attribute (see "Configuring classes for positional matching" on page 83).

The built-in types `bool`, `bytearray`, `bytes`, `dict`,[23] `float`, `frozenset`, `int`, `list`, `set`, `str`, and `tuple`, as well as any `namedtuple` and any `dataclass`, are all configured to take a single positional pattern, which is matched against the instance value. For example, the pattern `str(x)` matches any string and binds its value to *x* by matching the string's value against the capture pattern—as does `str() as x`.

You may remember a literal pattern example we presented earlier, showing that literal matching could not discriminate between the integer `42` and the float `42.0` because `42 == 42.0`. You can use class matching to overcome that issue:

```
>>> for subject in 42, 42.0:
...     match subject:
...         case int(x): print('integer', x)
...         case float(x): print('float', x)
...
integer 42
float 42.0
```

Once the type of the subject value has matched, for each of the named patterns *name=pattern*, Python retrieves the attribute *name* from the instance and matches its value against *pattern*. If all named pattern matches succeed, the whole match succeeds. Python handles positional patterns by converting them to named patterns, as you'll see momentarily.

Guards

When a **case** clause's pattern succeeds, it is often convenient to determine on the basis of values extracted from the match whether this **case** should execute. When a guard is present, it executes after a successful match. If the guard expression evaluates as false, Python abandons the current **case**, despite the match, and moves

23 And its subclasses, for example, `collections.defaultdict`.

on to consider the next case. This example uses a guard to exclude odd integers by checking the value bound in the match:

```
>>> for subject in range(5):
...     match subject:
...         case int(i) if i % 2 == 0: print(i, "is even")
...
0 is even
2 is even
4 is even
```

Configuring classes for positional matching

When you want your own classes to handle positional patterns in matching, you have to tell the interpreter which *attribute of the instance* (not which *argument to `__init__`*) each positional pattern corresponds to. You do this by setting the class's `__match_args__` attribute to a sequence of names. The interpreter raises a `TypeError` exception if you attempt to use more positional patterns than you defined:

```
>>> class Color:
...     __match_args__ = ('red', 'green', 'blue')
...     def __init__(self, r, g, b, name='anonymous'):
...         self.name = name
...         self.red, self.green, self.blue = r, g, b
...
>>> color_red = Color(255, 0, 0, 'red')
>>> color_blue = Color(0, 0, 255)
>>> for subject in (42.0, color_red, color_blue):
...     match subject:
...         case float(x):
...             print('float', x)
...         case Color(red, green, blue, name='red'):
...             print(type(subject).__name__, subject.name,
...                   red, green, blue)
...         case Color(red, green, 255) as color:
...             print(type(subject).__name__, color.name,
...                   red, green, color.blue)
...         case _: print(type(subject), subject)
...
float 42.0
Color red 255 0 0
Color anonymous 0 0 255
```

```
>>> match color_red:
...     case Color(red, green, blue, name):
...         print("matched")
...
```

```
Traceback (most recent call last):
  File "<stdin>", line 2, in <module>
TypeError: Color() accepts 3 positional sub-patterns (4 given)
```

The while Statement

The **while** statement repeats execution of a statement or block of statements for as long as a conditional expression evaluates as true. Here's the syntax of the **while** statement:

```
while expression:
    statement(s)
```

A **while** statement can also include an **else** clause and **break** and **continue** statements, all of which we'll discuss after we look at the **for** statement.

Here's a typical **while** statement:

```
count = 0
while x > 0:
    x //= 2            # floor division
    count += 1
print('The approximate log2 is', count)
```

First Python evaluates *expression*, which is known as the *loop condition*, in a Boolean context. When the condition evaluates as false, the **while** statement ends. When the loop condition evaluates as true, the statement or block of statements that make up the *loop body* executes. Once the loop body finishes executing, Python evaluates the loop condition again, to check whether another iteration should execute. This process continues until the loop condition evaluates as false, at which point the **while** statement ends.

The loop body should contain code that eventually makes the loop condition false, since otherwise the loop never ends (unless the body raises an exception or executes a **break** statement). A loop within a function's body also ends if the loop body executes a **return** statement, since in this case the whole function ends.

The for Statement

The **for** statement repeats execution of a statement or block of statements controlled by an iterable expression. Here's the syntax:

```
for target in iterable:
    statement(s)
```

The **in** keyword is part of the syntax of the **for** statement; its purpose here is distinct from the **in** operator, which tests membership.

Here's a rather typical **for** statement:

```
for letter in 'ciao':
    print(f'give me a {letter}...')
```

A **for** statement can also include an **else** clause and **break** and **continue** statements; we'll discuss all of these shortly, starting with "The else Clause on Loop Statements" on page 92. As mentioned previously, *iterable* may be any iterable Python expression. In particular, any sequence is iterable. The interpreter implicitly calls the built-in `iter` on the iterable, producing an *iterator* (discussed in the following subsection), which it then iterates over.

target is normally an identifier naming the *control variable* of the loop; the **for** statement successively rebinds this variable to each item of the iterator, in order. The statement or statements that make up the *loop body* execute once for each item in *iterable* (unless the loop ends because of an exception or a **break** or **return** statement). Since the loop body may terminate before the iterator is exhausted, this is one case in which you may use an *unbounded* iterable—one that, per se, would never cease yielding items.

You can also use a target with multiple identifiers, as in an unpacking assignment. In this case, the iterator's items must themselves be iterables, each with exactly as many items as there are identifiers in the target. For example, when *d* is a dictionary, this is a typical way to loop on the items (key/value pairs) in *d*:

```
for key, value in d.items():
    if key and value:          # print only truthy keys and values
        print(key, value)
```

The `items` method returns another kind of iterable (a *view*), whose items are key/value pairs; so, we use a **for** loop with two identifiers in the target to unpack each item into `key` and `value`.

Precisely *one* of the identifiers may be preceded by a star, in which case the starred identifier is bound to a list of all items not assigned to other targets. Although components of a target are commonly identifiers, values can be bound to any acceptable LHS expression, as covered in "Assignment Statements" on page 53—so, the following is correct, although not the most readable style:

```
prototype = [1, 'placeholder', 3]
for prototype[1] in 'xyz':
    print(prototype)
# prints [1, 'x', 3], then [1, 'y', 3], then [1, 'z', 3]
```

Don't Alter Mutable Objects While Looping on Them

When an iterator has a mutable underlying iterable, don't alter that underlying object during the execution of a **`for`** loop on the iterable. For example, the preceding key/value printing example cannot alter *d*. The `items` method returns a "view" iterable whose underlying object is *d*, so the loop body cannot mutate the set of keys in *d* (e.g., by executing **`del`** *d*[*key*]). To ensure that *d* is not the underlying object of the iterable, you may, for example, iterate over `list(`*d*`.items())` to allow the loop body to mutate *d*. Specifically:

- When looping on a list, do not insert, append, or delete items (rebinding an item at an existing index is OK).
- When looping on a dictionary, do not add or delete items (rebinding the value for an existing key is OK).
- When looping on a set, do not add or delete items (no alteration is permitted).

The loop body may rebind the control target variable(s), but the next iteration of the loop always rebinds them again. If the iterator yields no items, the loop body does not execute at all. In this case, the **`for`** statement does not bind or rebind its control variable in any way. If the iterator yields at least one item, however, then when the loop statement ends, the control variable remains bound to the last value to which the loop statement bound it. The following code is therefore correct *only* when `someseq` is not empty:

```
for x in someseq:
    process(x)
# potential NameError if someseq is empty
print(f'Last item processed was {x}')
```

Iterators

An *iterator* is an object *i* such that you can call `next(`*i*`)`, which returns the next item of iterator *i* or, when exhausted, raises a `StopIteration` exception. Alternatively, you can call `next(`*i*`, `*default*`)`, in which case, when iterator *i* has no more items, the call returns *default*.

When you write a class (see "Classes and Instances" on page 115), you can let instances of the class be iterators by defining a special method `__next__` that takes no argument except `self`, and returns the next item or raises `StopIteration`. Most iterators are built by implicit or explicit calls to the built-in function `iter`, covered in Table 8-2. Calling a generator also returns an iterator, as we discuss in "Generators" on page 109.

As pointed out previously, the **for** statement implicitly calls `iter` on its iterable to get an iterator. The statement:

```
for x in c:
    statement(s)
```

is exactly equivalent to:

```
_temporary_iterator = iter(c)
while True:
    try:
        x = next(_temporary_iterator)
    except StopIteration:
        break
    statement(s)
```

where *`_temporary_iterator`* is an arbitrary name not used elsewhere in the current scope.

Thus, when `iter(c)` returns an iterator *`i`* such that `next(i)` never raises `StopIteration` (an *unbounded iterator*), the loop **for** *x* **in** *c* continues indefinitely unless the loop body includes suitable **break** or **return** statements, or raises or propagates exceptions. `iter(c)`, in turn, calls the special method *`c`*`.__iter__()` to obtain and return an iterator on *c*. We'll talk more about `__iter__` in the following subsection and in "Container methods" on page 149.

Many of the best ways to build and manipulate iterators are found in the standard library module `itertools`, covered in "The itertools Module" on page 275.

Iterables versus iterators

Python's built-in sequences, like all iterables, implement an `__iter__` method, which the interpreter calls to produce an iterator over the iterable. Because each call to the built-in's `__iter__` method produces a new iterator, it is possible to nest multiple iterations over the same iterable:

```
>>> iterable = [1, 2]
>>> for i in iterable:
...     for j in iterable:
...         print(i, j)
...
1 1
1 2
2 1
2 2
```

Iterators also implement an `__iter__` method, but it always returns `self`, so nesting iterations over an iterator doesn't work as you might expect:

```
>>> iterator = iter([1, 2])
>>> for i in iterator:
...     for j in iterator:
```

```
...         print(i, j)
...
1 2
```

Here, both the inner and outer loops are iterating over the same iterator. By the time the inner loop first gets control, the first value from the iterator has already been consumed. The first iteration of the inner loop then exhausts the iterator, making both loops end upon attempting the next iteration.

range

Looping over a sequence of integers is a common task, so Python provides the built-in function `range` to generate an iterable over integers. The simplest way to loop *n* times in Python is:

```
for i in range(n):
    statement(s)
```

`range(x)` generates the consecutive integers from `0` (included) up to *x* (excluded). `range(x, y)` generates a list whose items are consecutive integers from *x* (included) up to *y* (excluded). `range(x, y, stride)` generates a list of integers from *x* (included) up to *y* (excluded), such that the difference between each two adjacent items is *stride*. If *stride* `< 0`, `range` counts down from *x* to *y*.

`range` generates an empty iterator when *x* `>=` *y* and *stride* `>0`, or when *x* `<=` *y* and *stride* `<0`. When *stride* `==0`, `range` raises an exception.

`range` returns a special-purpose object, intended just for use in iterations like the **`for`** statement shown previously. Note that `range` returns an iterable, not an iterator; you can easily obtain such an iterator, should you need one, by calling `iter(range(...))`. The special-purpose object returned by `range` consumes less memory (for wide ranges, *much* less memory) than the equivalent `list` object would. If you really need a `list` that's an arithmetic progression of `int`s, call `list(range(...))`. You will most often find that you don't, in fact, need such a complete list to be fully built in memory.

List comprehensions

A common use of a **`for`** loop is to inspect each item in an iterable and build a new list by appending the results of an expression computed on some or all of the items. The expression form known as a *list comprehension* or *listcomp* lets you code this common idiom concisely and directly. Since a list comprehension is an expression (rather than a block of statements), you can use it wherever you need an expression (e.g., as an argument in a function call, in a **`return`** statement, or as a subexpression of some other expression).

A list comprehension has the following syntax:

```
[ expression for target in iterable lc-clauses ]
```

`target` and *`iterable`* in each **`for`** clause of a list comprehension have the same syntax and meaning as those in a regular **`for`** statement, and the *`expression`* in each **`if`** clause of a list comprehension has the same syntax and meaning as the *`expression`* in a regular **`if`** statement. When *`expression`* denotes a tuple, you must enclose it in parentheses.

`lc-clauses` is a series of zero or more clauses, each with either this form:

```
for target in iterable
```

or this form:

```
if expression
```

A list comprehension is equivalent to a **`for`** loop that builds the same list by repeated calls to the resulting list's `append` method.[24] For example (assigning the list comprehension result to a variable for clarity), this:

```
result = [x+1 for x in some_sequence]
```

is just the same as the **`for`** loop:

```
result = []
for x in some_sequence:
    result.append(x+1)
```

Don't Build a List Unless You Need To

If you are just going to loop once over the items, you don't need an actual indexable list: use a generator expression instead (covered in "Generator expressions" on page 111). This avoids list creation and uses less memory. In particular, resist the temptation to use a list comprehension as a not particularly readable "single-line loop," like this:

```
[fn(x) for x in seq]
```

and then ignore the resulting list—just use a normal **for** loop instead!

Here's a list comprehension that uses an **`if`** clause:

```
result = [x+1 for x in some_sequence if x>23]
```

This list comprehension is the same as a **`for`** loop that contains an **`if`** statement:

```
result = []
for x in some_sequence:
    if x>23:
        result.append(x+1)
```

24 Except that the loop variables' scope is within the comprehension only, different from the way scoping works in a **`for`** statement.

Here's a list comprehension using a nested **for** clause to flatten a "list of lists" into a single list of items:

```
result = [x for sublist in listoflists for x in sublist]
```

This is the same as a **for** loop with another **for** loop nested inside:

```
result = []
for sublist in listoflists:
    for x in sublist:
        result.append(x)I
```

As these examples show, the order of **for** and **if** in a list comprehension, is the same as in the equivalent loop, but, in the list comprehension the nesting remains implicit. If you remember "order **for** clauses as in a nested loop," that can help you get the ordering of the list comprehension's clauses right.

> **List Comprehensions and Variable Scope**
>
> A list comprehension expression evaluates in its own scope (as do set and dictionary comprehensions, described in the following sections, and generator expressions, discussed toward the end of this chapter). When a `target` component in the **for** statement is a name, the name is defined solely within the expression scope and is not available outside it.

Set comprehensions

A *set comprehension* has exactly the same syntax and semantics as a list comprehension, except that you enclose it in braces (`{}`) rather than in brackets (`[]`). The result is a `set`; for example:

```
s = {n//2 for n in range(10)}
print(sorted(s))  # prints: [0, 1, 2, 3, 4]
```

A similar list comprehension would have each item repeated twice, but building a `set` removes duplicates.

Dictionary comprehensions

A *dictionary comprehension* has the same syntax as a set comprehension, except that instead of a single expression before the **for** clause, you use two expressions with a colon (`:`) between them: *`key`*`:`*`value`*. The result is a `dict`, which retains insertion order. For example:

```
d = {s: i for (i, s) in enumerate(['zero', 'one', 'two'])}
print(d)          # prints: {'zero': 0, 'one': 1, 'two': 2}
```

The break Statement

You can use a **break** statement *only* within a loop body. When **break** executes, the loop terminates *without executing any* ***else*** *clause on the loop*. When loops are nested, a **break** terminates only the innermost nested loop. In practice, a **break** is typically within a clause of an **if** (or, occasionally, **match**) statement in the loop body, so that **break** executes conditionally.

One common use of **break** is to implement a loop that decides whether it should keep looping only in the middle of each loop iteration (what Donald Knuth called the "loop and a half" structure in his great 1974 paper "Structured Programming with go to Statements"[25]). For example:

```
while True:          # this loop can never terminate "naturally"
    x = get_next()
    y = preprocess(x)
    if not keep_looping(x, y):
        break
    process(x, y)
```


The continue Statement

Like **break**, the **continue** statement can exist only within a loop body. It causes the current iteration of the loop body to terminate, and execution continues with the next iteration of the loop. In practice, a **continue** is usually within a clause of an **if** (or, occasionally, a **match**) statement in the loop body, so that **continue** executes conditionally.

Sometimes, a **continue** statement can take the place of nested **if** statements within a loop. For example, here each x has to pass multiple tests before being completely processed:

```
for x in some_container:
    if seems_ok(x):
        lowbound, highbound = bounds_to_test()
        if lowbound <= x < highbound:
            pre_process(x)
            if final_check(x):
                do_processing(x)
```

Nesting increases with the number of conditions. Equivalent code with **continue** "flattens" the logic:

```
for x in some_container:
    if not seems_ok(x):
        continue
    lowbound, highbound = bounds_to_test()
    if x < lowbound or x >= highbound:
        continue
    pre_process(x)
```

25 In that paper, Knuth also first proposed using "devices like indentation, rather than delimiters" to express program structure—just as Python does!

```
    if final_check(x):
        do_processing(x)
```

Flat Is Better Than Nested

Both versions work the same way, so which one you use is a matter of personal preference and style. One of the principles of The Zen of Python (which you can see at any time by typing **import this** at an interactive Python interpreter prompt) is "Flat is better than nested." The **continue** statement is just one way Python helps you move toward the goal of a less-nested structure in a loop, when you choose to follow this tip.

The else Clause on Loop Statements

while and **for** statements may optionally have a trailing **else** clause. The statement or block under that clause executes when the loop terminates *naturally* (at the end of the **for** iterator, or when the **while** loop condition becomes false), but not when the loop terminates *prematurely* (via **break**, **return**, or an exception). When a loop contains one or more **break** statements, you'll often want to check whether it terminates naturally or prematurely. You can use an **else** clause on the loop for this purpose:

```
for x in some_container:
    if is_ok(x):
        break  # item x is satisfactory, terminate loop
else:
    print('Beware: no satisfactory item was found in container')
    x = None
```

The pass Statement

The body of a Python compound statement cannot be empty; it must always contain at least one statement. You can use a **pass** statement, which performs no action, as an explicit placeholder when a statement is syntactically required but you have nothing to do. Here's an example of using **pass** in a conditional statement as a part of some rather convoluted logic to test mutually exclusive conditions:

```
if condition1(x):
    process1(x)
elif x>23 or (x<5 and condition2(x)):
    pass       # nothing to be done in this case
elif condition3(x):
    process3(x)
else:
    process_default(x)
```

Empty def or class Statements: Use a Docstring, Not pass

You can also use a docstring, covered in "Docstrings" on page 99, as the body of an otherwise empty **`def`** or **`class`** statement. When you do this, you do not need to also add a **`pass`** statement (you can do so if you wish, but it's not optimal Python style).

The try and raise Statements

Python supports exception handling with the **`try`** statement, which includes **`try`**, **`except`**, **`finally`**, and **`else`** clauses. Your code can also explicitly raise an exception with the **`raise`** statement. When code raises an exception, normal control flow of the program stops and Python looks for a suitable exception handler. We discuss all of this in detail in "Exception Propagation" on page 204.

The with Statement

A **`with`** statement can often be a more readable, useful alternative to the **`try`**/**`finally`** statement. We discuss it in detail in "The with Statement and Context Managers" on page 201. A good grasp of context managers can often help you structure your code more clearly without compromising efficiency.

Functions

Most statements in a typical Python program are part of some function. Code in a function body may be faster than at a module's top level, as covered in "Avoid exec and from ... import *" on page 556, so there are excellent practical reasons to put most of your code into functions—and there are no disadvantages: clarity, readability and code reusability all improve when you avoid having any substantial chunks of module-level code.

A *function* is a group of statements that execute upon request. Python provides many built-in functions and lets programmers define their own functions. A request to execute a function is known as a *function call*. When you call a function, you can pass arguments that specify data upon which the function performs its computation. In Python, a function always returns a result: either **`None`** or a value, the result of the computation. Functions defined within **`class`** statements are also known as *methods*. We cover issues specific to methods in "Bound and Unbound Methods" on page 126; the general coverage of functions in this section, however, also applies to methods.

Python is somewhat unusual in the flexibility it affords the programmer in defining and calling functions. This flexibility does mean that some constraints are not adequately expressed solely by the syntax. In Python, functions are objects (values), handled just like other objects. Thus, you can pass a function as an argument in a call to another function, and a function can return another function as the result of a call. A function, just like any other object, can be bound to a variable, can be an item in a container, and can be an attribute of an object. Functions can also be keys in a dictionary. The fact that functions are ordinary objects in Python is often expressed by saying that functions are *first-class* objects.

For example, given a `dict` keyed by functions, with the values being each function's inverse, you could make the dictionary bidirectional by adding the inverse values as keys, with their corresponding keys as values. Here's a small example of this idea, using some functions from the module `math` (covered in "The math and cmath Modules" on page 488), that takes a one-way mapping of inverse pairs and then adds the inverse of each entry to complete the mapping:

```
def add_inverses(i_dict):
    for f in list(i_dict):  # iterates over keys while mutating i_dict
        i_dict[i_dict[f]] = f
math_map = {sin:asin, cos:acos, tan:atan, log:exp}
add_inverses(math_map)
```

Note that in this case the function mutates its argument (whence its need to use a `list` call for looping). In Python, the usual convention is for such functions not to return a value (see "The return Statement" on page 100).

Defining Functions: The def Statement

The **`def`** statement is the usual way to create a function. **`def`** is a single-clause compound statement with the following syntax:

```
def function_name(parameters):
   statement(s)
```

`function_name` is an identifier, and the nonempty indented *`statement(s)`* are the *function body*. When the interpreter encounters a **`def`** statement, it compiles the function body, creating a function object, and binds (or rebinds, if there was an existing binding) *`function_name`* to the compiled function object in the containing namespace (typically the module namespace, or a class namespace when defining methods).

`parameters` is an optional list specifying the identifiers that will be bound to values that each function call provides. We distinguish between those identifiers, and the values provided for them in calls, as usual in computer science by referring to the former as *parameters* and the latter as *arguments*.

In the simplest case, a function defines no parameters, meaning the function won't accept any arguments when you call it. In this case, the **`def`** statement has empty parentheses after *`function_name`*, as must all calls. Otherwise, *`parameters`* will be a list of specifications (see "Parameters" on page 95). The function body does not execute when the **`def`** statement executes; rather, Python compiles it into bytecode, saves it as the function object's `__code__` attribute, and executes it later on each call to the function. The function body can contain zero or more occurrences of the **`return`** statement, as we'll discuss shortly.

Each call to the function supplies argument expressions corresponding to parameters in the function definition. The interpreter evaluates the argument expressions from left to right and creates a new namespace in which it binds the argument values to the parameter names as local variables of the function call (as we discuss in "Calling Functions" on page 101). Then Python executes the function body, with the function call namespace as the local namespace.

Here's a simple function that returns a value that is twice the value passed to it each time it's called:

```
def twice(x):
    return x*2
```

The argument can be anything that you can multiply by two, so you could call the function with a number, string, list, or tuple as an argument. Each call returns a new value of the same type as the argument: `twice('ciao')`, for example, returns `'ciaociao'`.

The number of parameters of a function, together with the parameters' names, the number of mandatory parameters, and the information on whether and where unmatched arguments should be collected, are a specification known as the function's *signature*. A signature defines how you can call the function.

Parameters

Parameters (pedantically, *formal parameters*) name the values passed into a function call, and may specify default values for them. Each time you call the function, the call binds each parameter name to the corresponding argument value in a new local namespace, which Python later destroys on function exit.

Besides letting you name individual arguments, Python also lets you collect argument values not matched by individual parameters, and lets you specifically require that some arguments be positional, or be named.

Positional parameters

A positional parameter is an identifier, *`name`*, which names the parameter. You use these names inside the function body to access the argument values to the call. Callers can normally provide values for these parameters with either positional or named arguments (see "Matching arguments to parameters" on page 104).

Named parameters

Named parameters normally take the form *`name=expression`* (**3.8+** or come after a positional argument collector, often just `*`, as discussed shortly). They are also often known (when written in the traditional *`name=expression`* form) as *default*, *optional*, and even—confusingly, since they do not involve any Python keywords—*keyword* parameters. When it executes a **`def`** statement, the interpreter evaluates each such *`expression`* and saves the resulting value, known as the *default value* for the parameter, among the attributes of the function object. A function call thus need not provide an argument value for a named parameter written in the traditional form: the call uses the default value given as the *`expression`*. You may provide positional arguments as values for some named parameters (3.8+ except for parameters that are identified as named ones by appearing after a positional argument collector; see also “Matching arguments to parameters” on page 104).

Python computes each default value *exactly once*, when the **def** statement executes, *not* each time you call the resulting function. In particular, this means that Python binds exactly the *same* object, the default value, to the named parameter whenever the caller does not supply a corresponding argument.

> **Avoid Mutable Default Values**
>
> A function can alter a mutable default value, such as a list, each time you call the function without an argument corresponding to the respective parameter. This is usually not the behavior you want; for details, see “Mutable default parameter values” on page 97.

Positional-only marker

3.8+ A function’s signature may contain a single *positional-only marker* (`/`) as a dummy parameter. The parameters preceding the marker are known as *positional-only parameters*, and *must* be provided as positional arguments, *not* named arguments, when calling the function; using named arguments for these parameters raises a `TypeError` exception.

The built-in `int` type, for example, has the following signature:

```
int(x, /, base=10)
```

When calling `int`, you must pass a value for x and you must pass it positionally. `base` (used when `x` is a string to be converted to `int`) is optional, and you may pass it either positionally or as a named argument (it’s an error to pass `x` as a number and also pass `base`, but the notation cannot capture that quirk).

Positional argument collector

The positional argument collector can take one of two forms, either `*`*`name`* or 3.8+ just `*`. In the former case, *`name`* is bound at call time to a tuple of unmatched positional arguments (when all positional arguments are matched, the tuple is empty). In the latter case (the `*` is a dummy parameter), a call with unmatched positional arguments raises a `TypeError` exception.

When a function’s signature has either kind of positional argument collector, no call can provide a positional argument for a named parameter coming after the collector: the collector prohibits (in the `*` form) or gives a destination for (in the `*`*`name`* form) positional arguments that do not correspond to parameters coming before it.

For example, consider this function from the `random` module:

```
def sample(population, k, *, counts=None):
```

When calling `sample`, values for `population` and `k` are required, and may be passed positionally or by name. `counts` is optional; if you do pass it, you must pass it as a named argument.

Named argument collector

This final, optional parameter specification has the form `**name`. When the function is called, *`name`* is bound to a dictionary whose items are the `(key, value)` pairs of any unmatched named arguments, or an empty dictionary if there are no such arguments.

Parameter sequence

Generally speaking, positional parameters are followed by named parameters, with the positional and named argument collectors (if present) last. The positional-only marker, however, may appear at any position in the list of parameters.

Mutable default parameter values

When a named parameter's default value is a mutable object, and the function body alters the parameter, things get tricky. For example:

```
def f(x, y=[]):
    y.append(x)
    return id(y), y
print(f(23))                # prints: (4302354376, [23])
print(f(42))                # prints: (4302354376, [23, 42])
```

The second `print` prints `[23, 42]` because the first call to `f` altered the default value of `y`, originally an empty list `[]`, by appending `23` to it. The `id` values (always equal to each other, although otherwise arbitrary) confirm that both calls return the same object. If you want `y` to be a new, empty list object, each time you call `f` with a single argument (a far more frequent need!), use the following idiom instead:

```
def f(x, y=None):
    if y is None:
        y = []
    y.append(x)
    return id(y), y
print(f(23))                # prints: (4302354376, [23])
print(f(42))                # prints: (4302180040, [42])
```

There may be cases in which you explicitly want a mutable default parameter value that is preserved across multiple function calls, most often for caching purposes, as in the following example:

```
def cached_compute(x, _cache={}):
    if x not in _cache:
        _cache[x] = costly_computation(x)
    return _cache[x]
```

Such caching behavior (also known as *memoization*) is usually best obtained by decorating the underlying `costly_computation` function with `functools.lru_cache`, covered in Table 8-7 and discussed in detail in Chapter 17.

Argument collector parameters

The presence of argument collectors (the special forms `*`, `*name`, or `**name`) in a function's signature allows a function to prohibit (`*`) or collect positional (`*name`) or named (`**name`) arguments that do not match any parameters (see "Matching arguments to parameters" on page 104). There is no requirement to use specific names—you can use any identifier you want in each special form. `*args` and `**kwds` or `**kwargs`, as well as `*a` and `**k`, are popular choices.

The presence of the special form `*` causes calls with unmatched positional arguments to raise a `TypeError` exception.

`*args` specifies that any extra positional arguments to a call (i.e., positional arguments not matching positional parameters in the function signature) get collected into a (possibly empty) tuple, bound in the call's local namespace to the name `args`. Without a positional argument collector, unmatched positional arguments raise a `TypeError` exception.

For example, here's a function that accepts any number of positional arguments and returns their sum (and demonstrates the use of an identifier other than `*args`):

```
def sum_sequence(*numbers):
    return sum(numbers)
print(sum_sequence(23, 42))        # prints: 65
```

Similarly, `**kwds` specifies that any extra named arguments (i.e., those named arguments not explicitly specified in the signature) get collected into a (possibly empty) dictionary whose items are the names and values of those arguments, bound to the name `kwds` in the function call namespace.

For example, the following function takes a dictionary whose keys are strings and whose values are numeric, and adds given amounts to certain values:

```
def inc_dict(d, **values):
    for key, value in values.items():
        if key in d:
            d[key] += value
        else:
            d[key] = value

my_dict = {'one': 1, 'two': 2}

inc_dict(my_dict, one=3, new=42)
print(my_dict)                # prints: {'one': 4, 'two': 2, 'new':42}
```

Without a named argument collector, unmatched named arguments raise a `TypeError` exception.

Attributes of Function Objects

The **def** statement sets some attributes of a function object *f*. The string attribute *f*.__name__ is the identifier that **def** uses as the function's name. You may rebind __name__ to any string value, but trying to unbind it raises a TypeError exception. *f*.__defaults__, which you may freely rebind or unbind, is the tuple of default values for named parameters (empty, if the function has no named parameters).

Docstrings

Another function attribute is the *documentation string*, or *docstring*. You may use or rebind a function *f*'s docstring attribute as *f*.__doc__. When the first statement in the function body is a string literal, the compiler binds that string as the function's docstring attribute. A similar rule applies to classes and modules (see "Class documentation strings" on page 119 and "Module documentation strings" on page 225). Docstrings can span multiple physical lines, so it's best to specify them in triple-quoted string literal form. For example:

```
def sum_sequence(*numbers):
    """Return the sum of multiple numerical arguments.

       The arguments are zero or more numbers.
       The result is their sum.
    """
    return sum(numbers)
```

Documentation strings should be part of any Python code you write. They play a role similar to that of comments, but they are even more useful, since they remain available at runtime (unless you run your program with **python -OO**, as covered in "Command-Line Syntax and Options" on page 22). Python's help function (see "Interactive Sessions" on page 25), development environments, and other tools can use the docstrings from function, class, and module objects to remind the programmer how to use those objects. The doctest module (covered in "The doctest Module" on page 517) makes it easy to check that sample code present in docstrings, if any, is accurate and correct, and remains so as the code and docs get edited and maintained.

To make your docstrings as useful as possible, respect a few simple conventions, as detailed in PEP 257. The first line of a docstring should be a concise summary of the function's purpose, starting with an uppercase letter and ending with a period. It should not mention the function's name, unless the name happens to be a natural-language word that comes naturally as part of a good, concise summary of the function's operation. Use imperative rather than descriptive form: e.g., say "Return xyz…" rather than "Returns xyz…" If the docstring is multiline, the second line should be empty, and the following lines should form one or more paragraphs, separated by empty lines, describing the function's parameters, preconditions, return value, and side effects (if any). Further explanations, bibliographical references, and usage examples—which you should always check with doctest—can optionally (and often very usefully!) follow toward the end of the docstring.

Other attributes of function objects

In addition to its predefined attributes, a function object may have other arbitrary attributes. To create an attribute of a function object, bind a value to the appropriate attribute reference in an assignment statement after the **def** statement executes. For example, a function could count how many times it gets called:

```
def counter():
    counter.count += 1
    return counter.count
counter.count = 0
```

Note that this is *not* common usage. More often, when you want to group together some state (data) and some behavior (code), you should use the object-oriented mechanisms covered in Chapter 4. However, the ability to associate arbitrary attributes with a function can sometimes come in handy.

Function Annotations

Every parameter in a **def** clause can be *annotated* with an arbitrary expression—that is, wherever within the **def**'s parameter list you can use an identifier, you can alternatively use the form `*identifier*:*expression*`, and the expression's value becomes the *annotation* for that parameter.

You can also annotate the return value of the function, using the form `->*expression*` between the `)` of the **def** clause and the `:` that ends the **def** clause; the expression's value becomes the annotation for the name `'return'`. For example:

```
>>> def f(a:'foo', b)->'bar': pass
...
>>> f.__annotations__
{'a': 'foo', 'return': 'bar'}
```

As shown in this example, the `__annotations__` attribute of the function object is a `dict` mapping each annotated identifier to the respective annotation.

You can currently, in theory, use annotations for whatever purpose you wish: Python itself does nothing with them, except construct the `__annotations__` attribute. For detailed information about annotations used for type hinting, which is now normally considered their key use, see Chapter 5.

The return Statement

You can use the **return** keyword in Python only inside a function body, and you can optionally follow it with an expression. When **return** executes, the function terminates, and the value of the expression is the function's result. A function returns **None** when it terminates by reaching the end of its body, or by executing a **return** statement with no expression (or by explicitly executing **return None**).

Good Style in return Statements

As a matter of good style, when some **return** statements in a function have an expression, then *all* **return** statements in the function should have an expression. **return None** should only ever be written explicitly to meet this style requirement. *Never* write a **return** statement without an expression at the end of a function body. Python does not enforce these stylistic conventions, but your code is clearer and more readable when you follow them.

Calling Functions

A function call is an expression with the following syntax:

```
function_object(arguments)
```

function_object may be any reference to a function (or other callable) object; most often, it's just the function's name. The parentheses denote the function call operation itself. *arguments*, in the simplest case, is a series of zero or more expressions separated by commas (`,`), giving values for the function's corresponding parameters. When the function call executes, the parameters are bound to the argument values in a new namespace, the function body executes, and the value of the function call expression is whatever the function returns. Objects created inside and returned by the function are liable to garbage collection unless the caller retains a reference to them.

Don't Forget the Trailing () to Call a Function

Just *mentioning* a function (or other callable object) does *not*, per se, call it. To *call* a function (or other object) without arguments, you *must* use `()` after the function's name (or other reference to the callable object).

Positional and named arguments

Arguments can be of two types. *Positional* arguments are simple expressions; *named* (also known, alas, as *keyword*[26]) arguments take the form:

```
identifier=expression
```

It is a syntax error for named arguments to precede positional ones in a function call. Zero or more positional arguments may be followed by zero or more named arguments. Each positional argument supplies the value for the parameter that corresponds to it by position (order) in the function definition. There is no requirement for positional arguments to match positional parameters, or vice versa—if there are more positional arguments than positional parameters, the additional

26 "Alas" because they have nothing to do with Python keywords, so the terminology is confusing; if you use an actual Python keyword to name a named parameter, that raises `SyntaxError`.

arguments are bound by position to named parameters, if any, for all parameters preceding an argument collector in the signature. For example:

```
def f(a, b, c=23, d=42, *x):
    print(a, b, c, d, x)
f(1,2,3,4,5,6)  # prints: 1 2 3 4 (5, 6)
```

Note that it matters where in the function signature the argument collector appears (see "Matching arguments to parameters" on page 104 for all the gory details):

```
def f(a, b, *x, c=23, d=42):
    print(a, b, x, c, d)
f(1,2,3,4,5,6)  # prints: 1 2 (3, 4, 5, 6) 23 42
```

In the absence of any named argument collector (`**name`) parameter, each argument's name must be one of the parameter names used in the function's signature.[27] The *`expression`* supplies the value for the parameter of that name. Many built-in functions do not accept named arguments: you must call such functions with positional arguments only. However, functions coded in Python usually accept named as well as positional arguments, so you may call them in different ways. Positional parameters can be matched by named arguments, in the absence of matching positional arguments.

A function call must supply, via a positional or a named argument, exactly one value for each mandatory parameter, and zero or one value for each optional parameter.[28] For example:

```
def divide(divisor, dividend=94):
    return dividend // divisor
print(divide(12))                          # prints: 7
print(divide(12, 94))                      # prints: 7
print(divide(dividend=94, divisor=12))     # prints: 7
print(divide(divisor=12))                  # prints: 7
```

As you can see, the four calls to `divide` here are equivalent. You can pass named arguments for readability purposes whenever you think that identifying the role of each argument and controlling the order of arguments enhances your code's clarity.

A common use of named arguments is to bind some optional parameters to specific values, while letting other optional parameters take default values:

```
def f(middle, begin='init', end='finis'):
    return begin+middle+end
print(f('tini', end=''))                   # prints: inittini
```

With the named argument `end=''`, the caller specifies a value (the empty string `''`) for `f`'s third parameter, `end`, and still lets *f*'s second parameter, `begin`, use its

27 Python developers introduced positional-only arguments when they realized that parameters to many built-in functions effectively had no valid names as far as the interpreter was concerned.

28 An "optional parameter" being one for which the function's signature supplies a default value.

default value, the string `'init'`. You may pass the arguments as positional even when parameters are named; for example, with the preceding function:

```
print(f('a','c','t'))                          # prints: cat
```

At the end of the arguments in a function call, you may optionally use either or both of the special forms `*seq` and `**dct`. If both forms are present, the form with two asterisks must be last. `*seq` passes the items of iterable `seq` to the function as positional arguments (after the normal positional arguments, if any, that the call gives with the usual syntax). `seq` may be any iterable. `**dct` passes the items of `dct` to the function as named arguments, where `dct` must be a mapping whose keys are all strings. Each item's key is a parameter name, and the item's value is the argument's value.

You may want to pass an argument of the form `*seq` or `**dct` when the parameters use similar forms, as discussed in "Parameters" on page 95. For example, using the function `sum_sequence` defined in that section (and shown again here), you may want to print the sum of all the values in the dictionary `d`. This is easy with `*seq`:

```
def sum_sequence(*numbers):
    return sum(numbers)

d = {'a': 1, 'b': 100, 'c': 1000}
print(sum_sequence(*d.values()))
```

(Of course, `print(sum(d.values()))` would be simpler and more direct.)

A function call may have zero or more occurrences of `*seq` and/or `**dct`, as specified in PEP 448. You may even pass `*seq` or `**dct` when calling a function that does not use the corresponding form in its signature. In that case, you must ensure that the iterable `seq` has the right number of items, or that the dictionary `dct` uses the right identifier strings as keys; otherwise, the call raises an exception. As noted in the following section, a positional argument *cannot* match a "keyword-only" parameter; only a named argument, explicit or passed via `**kwargs`, can do that.

"Keyword-only" parameters

Parameters after a positional argument collector (`*name` or **3.8+** `*`) in the function's signature are known as *keyword-only parameters*: the corresponding arguments, if any, *must* be named arguments. In the absence of any match by name, such a parameter is bound to its default value, as set at function definition time.

Keyword-only parameters can be either positional or named. However, you *must* pass them as named arguments, not as positional ones. It's more usual and readable to have simple identifiers, if any, at the start of the keyword-only parameter specifications, and `identifier=default` forms, if any, following them, though this is not a requirement of the Python language.

Functions requiring keyword-only parameter specifications *without* collecting "surplus" positional arguments indicate the start of the keyword-only parameter specifications with a dummy parameter consisting solely of an asterisk (*), to which no argument corresponds. For example:

```
def f(a, *, b, c=56):  # b and c are keyword only
    return a, b, c
f(12, b=34)  # Returns (12, 34, 56) c is optional, it has a default
f(12)        # Raises a TypeError exception, since you didn't pass b
# Error message is: missing 1 required keyword-only argument: 'b'
```

If you also specify the special form `**`*`kwds`*, it must come at the end of the parameter list (after the keyword-only parameter specifications, if any). For example:

```
def g(x, *a, b=23, **k):  # b is keyword only
    return x, a, b, k
g(1, 2, 3, c=99)          # Returns (1, (2, 3), 23, {'c': 99})
```

Matching arguments to parameters

A call *must* provide an argument for all positional parameters, and *may* do so for named parameters that are not keyword only.

The matching proceeds as follows:

1. Arguments of the form `*`*`expression`* are internally replaced by a sequence of positional arguments obtained by iterating over *`expression`*.
2. Arguments of the form `**`*`expression`* are internally replaced by a sequence of keyword arguments whose names and values are obtained by iterating over *`expression`*'s `items()`.
3. Say that the function has *N* positional parameters and the call has *M* positional arguments:
   - When *M*≤*N*, bind all the positional arguments to the first *M* positional parameter names; the remaining positional parameters, if any, *must* be matched by named arguments.
   - When *M*>*N*, bind the remaining positional arguments to named parameters *in the order in which they appear in the signature*. This process terminates in one of three ways:
     1. All positional arguments have been bound.
     2. The next item in the signature is a `*` argument collector: the interpreter raises a `TypeError` exception.
     3. The next item in the signature is a `*`*`name`* argument collector: the remaining positional arguments are collected in a tuple that is then bound to *`name`* in the function call namespace.
4. The named arguments are then matched, in the order of the arguments' occurrences in the call, by name with the parameters—both positional and named. Attempts to rebind an already bound parameter name raise a `TypeError` exception.

5. If unmatched named arguments remain at this stage:
   - When the function signature includes a `**name` collector, the interpreter creates a dictionary with key/value pairs (`argument's_name, argument's_value`), and binds it to `name` in the function call namespace.
   - In the absence of such an argument collector, Python raises a `TypeError` exception.
6. Any remaining unmatched named parameters are bound to their default values.

At this point, the function call namespace is fully populated, and the interpreter executes the function's body using that "call namespace" as the local namespace for the function.

The semantics of argument passing

In traditional terms, all argument passing in Python is *by value* (although, in modern terminology, to say that argument passing is *by object reference* is more precise and accurate; check out the synonym *call by sharing*). When you pass a variable as an argument, Python passes to the function the object (value) to which the variable currently refers (not "the variable itself"!), binding this object to the parameter name in the function call namespace. Thus, a function *cannot* rebind the caller's variables. Passing a mutable object as an argument, however, allows the function to make changes to that object, because Python passes a reference to the object itself, not a copy. Rebinding a variable and mutating an object are totally disjoint concepts. For example:

```
def f(x, y):
    x = 23
    y.append(42)
a = 77
b = [99]
f(a, b)
print(a, b)             # prints: 77 [99, 42]
```

`print` shows that `a` is still bound to `77`. Function `f`'s rebinding of its parameter `x` to `23` has no effect on `f`'s caller, nor, in particular, on the binding of the caller's variable that happened to be used to pass `77` as the parameter's value. However, `print` also shows that `b` is now bound to `[99, 42]`. `b` is still bound to the same list object as before the call, but `f` has appended `42` to that list object, mutating it. In neither case has `f` altered the caller's bindings, nor can `f` alter the number `77`, since numbers are immutable. `f` can alter a list object, though, since list objects are mutable.

Namespaces

A function's parameters, plus any names that are bound (by assignment or by other binding statements, such as **`def`**) in the function body, make up the function's *local namespace*, also known as its *local scope*. Each of these variables is known as a *local variable* of the function.

Variables that are not local are known as *global variables* (in the absence of nested function definitions, which we'll discuss shortly). Global variables are attributes of the module object, as covered in "Attributes of module objects" on page 223. Whenever a function's local variable has the same name as a global variable, that name, within the function body, refers to the local variable, not the global one. We express this by saying that the local variable *hides* the global variable of the same name throughout the function body.

The global statement

By default, any variable bound in a function body is local to the function. If a function needs to bind or rebind some global variables (*not* best practice!), the first statement of the function's body must be:

```
global identifiers
```

where *`identifiers`* is one or more identifiers separated by commas (`,`). The identifiers listed in a **`global`** statement refer to the global variables (i.e., attributes of the module object) that the function needs to bind or rebind. For example, the function `counter` that we saw in "Other attributes of function objects" on page 100 could be implemented using **`global`** and a global variable, rather than an attribute of the function object:

```
_count = 0
def counter():
    global _count
    _count += 1
    return _count
```

Without the **`global`** statement, the `counter` function would raise an `UnboundLocalError` exception when called, because `_count` would then be an uninitialized (unbound) local variable. While the **`global`** statement enables this kind of programming, this style is inelegant and ill-advised. As we mentioned earlier, when you want to group together some state and some behavior, the object-oriented mechanisms covered in Chapter 4 are usually best.

Eschew global

Never use **`global`** if the function body just *uses* a global variable (including mutating the object bound to that variable, when the object is mutable). Use a **`global`** statement only if the function body *rebinds* a global variable (generally by assigning to the variable's name). As a matter of style, don't use **`global`** unless it's strictly necessary, as its presence causes readers of your program to assume the statement is there for some useful purpose. Never use **`global`** except as the first statement in a function body.

Nested functions and nested scopes

A **def** statement within a function body defines a *nested function*, and the function whose body includes the **def** is known as an *outer function* to the nested one. Code in a nested function's body may access (but *not* rebind) local variables of an outer function, also known as *free variables* of the nested function.

The simplest way to let a nested function access a value is often not to rely on nested scopes, but rather to pass that value explicitly as one of the function's arguments. If need be, you can bind the argument's value at nested-function **def** time: just use the value as the default for an optional argument. For example:

```
def percent1(a, b, c):
    def pc(x, total=a+b+c):
        return (x*100.0) / total
    print('Percentages are:', pc(a), pc(b), pc(c))
```

Here's the same functionality using nested scopes:

```
def percent2(a, b, c):
    def pc(x):
        return (x*100.0) / (a+b+c)
    print('Percentages are:', pc(a), pc(b), pc(c))
```

In this specific case, `percent1` has one tiny advantage: the computation of `a+b+c` happens only once, while `percent2`'s inner function `pc` repeats the computation three times. However, when the outer function rebinds local variables between calls to the nested function, repeating the computation can be necessary: be aware of both approaches, and choose the appropriate one on a case-by-case basis.

A nested function that accesses values from local variables of "outer" (containing) functions is also known as a *closure*. The following example shows how to build a closure:

```
def make_adder(augend):
    def add(addend):
        return addend+augend
    return add
add5 = make_adder(5)
add9 = make_adder(9)

print(add5(100))    # prints: 105
print(add9(100))    # prints: 109
```

Closures are sometimes an exception to the general rule that the object-oriented mechanisms covered in the next chapter are the best way to bundle together data and code. When you specifically need to construct callable objects, with some parameters fixed at object construction time, closures can be simpler and more direct than classes. For example, the result of `make_adder(7)` is a function that accepts a single argument and returns `7` plus that argument. An outer function that returns a closure is a "factory" for members of a family of functions distinguished by some parameters, such as the value of the argument `augend` in the previous example, which may often help you avoid code duplication.

The **`nonlocal`** keyword acts similarly to **`global`**, but it refers to a name in the namespace of some lexically surrounding function. When it occurs in a function definition nested several levels deep (a rarely needed structure!), the compiler searches the namespace of the most deeply nested containing function, then the function containing that one, and so on, until the name is found or there are no further containing functions, in which case the compiler raises an error (a global name, if any, does not match).

Here's a nested functions approach to the "counter" functionality we implemented in previous sections using a function attribute, then a global variable:

```
def make_counter():
    count = 0
    def counter():
        nonlocal count
        count += 1
        return count
    return counter

c1 = make_counter()
c2 = make_counter()
print(c1(), c1(), c1())     # prints: 1 2 3
print(c2(), c2())           # prints: 1 2
print(c1(), c2(), c1())     # prints: 4 3 5
```

A key advantage of this approach versus the previous ones is that these two nested functions, just like an object-oriented approach would, let you make independent counters—here `c1` and `c2`. Each closure keeps its own state and doesn't interfere with the other one.

lambda Expressions

If a function body is a single **`return`** *`expression`* statement, you may (*very* optionally!) choose to replace the function with the special **`lambda`** expression form:

```
lambda parameters: expression
```

A **`lambda`** expression is the anonymous equivalent of a normal function whose body is a single **`return`** statement. The **`lambda`** syntax does not use the **`return`** keyword. You can use a **`lambda`** expression wherever you could use a reference to a function. **`lambda`** can sometimes be handy when you want to use an *extremely simple* function as an argument or return value.

Here's an example that uses a **`lambda`** expression as an argument to the built-in `sorted` function (covered in Table 8-2):

```
a_list = [-2, -1, 0, 1, 2]
sorted(a_list, key=lambda x: x * x)  # returns: [0, -1, 1, -2, 2]
```

Alternatively, you can always use a local **def** statement to give the function object a name, then use this name as an argument or return value. Here's the same `sorted` example using a local **def** statement:

```
a_list = [-2, -1, 0, 1, 2]
def square(value):
    return value * value
sorted(a_list, key=square)          # returns: [0, -1, 1, -2, 2]
```

While **lambda** can at times be handy, **def** is usually better: it's more general and helps you make your code more readable, since you can choose a clear name for the function.

Generators

When the body of a function contains one or more occurrences of the keyword **yield**, the function is known as a *generator*, or more precisely a *generator function*. When you call a generator, the function body does not execute. Instead, the generator function returns a special iterator object, known as a *generator object* (sometimes, quite confusingly, also called just "a generator"), wrapping the function body, its local variables (including parameters), and the current point of execution (initially, the start of the function).

When you (implicitly or explicitly) call `next` on a generator object, the function body executes from the current point up to the next **yield**, which takes the form:

```
yield expression
```

A bare **yield** without the expression is also legal, and equivalent to **yield None**. When **yield** executes, the function execution is "frozen," preserving the current point of execution and local variables, and the expression following **yield** becomes the result of `next`. When you call `next` again, execution of the function body resumes where it left off, again up to the next **yield**. When the function body ends, or executes a **return** statement, the iterator raises a `StopIteration` exception to indicate that the iteration is finished. The expression after **return**, if any, is the argument to the `StopIteration` exception.

yield is an expression, not a statement. When you call `g.send(value)` on a generator object *g*, the value of **yield** is *value*; when you call `next(g)`, the value of **yield** is **None**. We'll talk more about this shortly: it's an elementary building block for implementing coroutines in Python.

A generator function is often a handy way to build an iterator. Since the most common way to use an iterator is to loop on it with a **for** statement, you typically call a generator like this (with the call to `next` being implicit in the **for** statement):

```
for avariable in somegenerator(arguments):
```

For example, say that you want a sequence of numbers counting up from `1` to *N* and then down to `1` again. A generator can help:

```python
def updown(N):
    for x in range(1, N):
        yield x
    for x in range(N, 0, -1):
        yield x
for i in updown(3):
    print(i)              # prints: 1 2 3 2 1
```

Here is a generator that works somewhat like built-in `range`, but returns an iterator on floating-point values rather than on integers:

```python
def frange(start, stop, stride=1.0):
    start = float(start)  # force all yielded values to be floats
    while start < stop:
        yield start
        start += stride
```

This example is only *somewhat* like `range` because, for simplicity, it makes the arguments `start` and `stop` mandatory, and assumes that `stride` is positive.

Generator functions are more flexible than functions that return lists. A generator function may return an unbounded iterator, meaning one that yields an infinite stream of results (to use only in loops that terminate by other means, e.g., via a conditionally executed **`break`** statement). Further, a generator object iterator performs *lazy evaluation*: the iterator can compute each successive item only when and if needed, "just in time," while the equivalent function does all computations in advance and may require large amounts of memory to hold the results list. Therefore, if all you need is the ability to iterate on a computed sequence, it is usually best to compute the sequence in a generator object, rather than in a function returning a list. If the caller needs a list of all the items produced by some bounded generator object built by *`g`*`(`*`arguments`*`)`, the caller can simply use the following code to explicitly request that Python build a list:

```python
resulting_list = list(g(arguments))
```

yield from

To improve execution efficiency and clarity when multiple levels of iteration are yielding values, you can use the form **`yield from`** *`expression`*, where *`expression`* is iterable. This yields the values from *`expression`* one at a time into the calling environment, avoiding the need to **`yield`** repeatedly. We can thus simplify the `updown` generator we defined earlier:

```python
def updown(N):
    yield from range(1, N)
    yield from range(N, 0, -1)
for i in updown(3):
    print(i)              # prints: 1 2 3 2 1
```

Moreover, using **`yield from`** lets you use generators as *coroutines*, discussed next.

Generators as near-coroutines

Generators are further enhanced with the possibility of receiving a value (or an exception) back from the caller as each **yield** executes. This lets generators implement coroutines, as explained in PEP 342. When a generator object resumes (i.e., you call `next` on it), the corresponding **yield**'s value is **None**. To pass a value *x* into some generator object *g* (so that *g* receives *x* as the value of the **yield** on which it's suspended), instead of calling `next(g)`, call `g.send(x)` (`g.send(None)` is just like `next(g)`).

Other enhancements to generators regard exceptions: we cover them in "Generators and Exceptions" on page 203.

Generator expressions

Python offers an even simpler way to code particularly simple generators: *generator expressions*, commonly known as *genexps*. The syntax of a genexp is just like that of a list comprehension (as covered in "List comprehensions" on page 88), except that a genexp is within parentheses (`()`) instead of brackets (`[]`). The semantics of a genexp are the same as those of the corresponding list comprehension, except that a genexp produces an iterator yielding one item at a time, while a list comprehension produces a list of all results in memory (therefore, using a genexp, when appropriate, saves memory). For example, to sum the squares of all single-digit integers, you could code `sum([x*x for x in range(10)])`, but you can express this better as `sum(x*x for x in range(10))` (just the same, but omitting the brackets): you get the same result but consume less memory. The parentheses that indicate the function call also do "double duty" and enclose the genexp. Parentheses are, however, required when the genexp is not the sole argument. Additional parentheses don't hurt, but are usually best omitted, for clarity.

Warning: Don't Iterate over a Generator Multiple Times

A limitation of generators and generator expressions is that you can iterate over them only once. Calling `next` on a generator that has been consumed will just raise `StopIteration` again, which most functions will take as an indication that the generator returns no values. If your code is not careful about reusing a consumed generator, this can introduce bugs:

```
# create a generator and list its items and their sum
squares = (x*x for x in range(5))
print(list(squares))  # prints [0, 1, 4, 9, 16]
print(sum(squares))   # Bug! Prints 0
```

You can write code to guard against accidentally iterating over a consumed generator by using a class to wrap the generator, like the following:

```
class ConsumedGeneratorError(Exception):
    """Raised if a generator is accessed after
       already consumed.
```

```
    """

class StrictGenerator:
    """Wrapper for generator that will only permit it
       to be consumed once. Additional accesses will
       raise ConsumedGeneratorError.
    """
    def __init__(self, gen):
        self._gen = gen
        self._gen_consumed = False
    def __iter__(self):
        return self
    def __next__(self):
        try:
            return next(self._gen)
        except StopIteration:
            if self._gen_consumed:
                raise ConsumedGeneratorError() from None
            self._gen_consumed = True
            raise
```

Now an erroneous reuse of a generator will raise an exception:

```
squares = StrictGenerator(x*x for x in range(5))
print(list(squares))  # prints: [0, 1, 4, 9, 16]
print(sum(squares))   # raises ConsumedGeneratorError
```

Recursion

Python supports recursion (i.e., a Python function can call itself, directly or indirectly), but there is a limit to how deep the recursion can go. By default, Python interrupts recursion and raises a `RecursionLimitExceeded` exception (covered in "Standard Exception Classes" on page 207) when it detects that recursion has exceeded a depth of 1,000. You can change this default recursion limit by calling the `setrecursionlimit` function in the module `sys`, covered in Table 8-3.

Note that changing the recursion limit does not give you unlimited recursion. The absolute maximum limit depends on the platform on which your program is running, and particularly on the underlying operating system and C runtime library, but it's typically a few thousand levels. If recursive calls get too deep, your program crashes. Such runaway recursion, after a call to `setrecursionlimit` that exceeds the platform's capabilities, is one of the few things that can cause a Python program to crash—really crash, hard, without the usual safety net of Python's exception mechanism. Therefore, beware of "fixing" a program that is getting `RecursionLimitExceeded` exceptions by raising the recursion limit with `setrecursionlimit`. While this *is* a valid technique, most often you're better advised to look for ways to remove the recursion unless you are confident you've been able to limit the depth of recursion that your program needs.

Readers who are familiar with Lisp, Scheme, or functional programming languages must in particular be aware that Python does *not* implement the optimization of *tail-call elimination*, which is so crucial in those languages. In Python, any call, recursive or not, has the same "cost" in terms of both time and memory space, dependent only on the number of arguments: the cost does not change, whether the call is a "tail call" (meaning that it's the last operation that the caller executes) or not. This makes recursion removal even more important.

For example, consider a classic use for recursion: walking a binary tree. Suppose you represent a binary tree structure as nodes, where each node is a three-item tuple `(payload, left, right)`, and `left` and `right` are either similar tuples or **`None`**, representing the left-side and right-side descendants. A simple example might be `(23, (42, (5, None, None), (55, None, None)), (94, None, None))` to represent the tree shown in Figure 3-1.

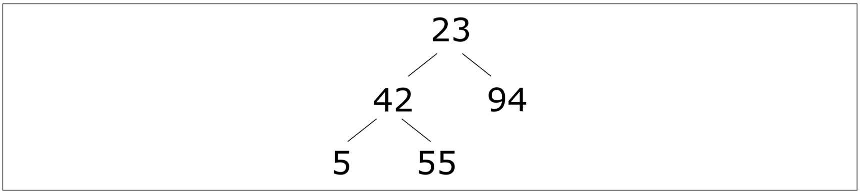


Figure 3-1. An example of a binary tree

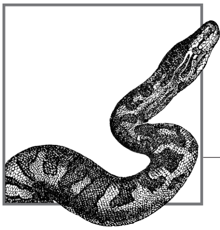
To write a generator function that, given the root of such a tree, "walks" the tree, yielding each payload in top-down order, the simplest approach is recursion:

```
def rec(t):
    yield t[0]
    for i in (1, 2):
        if t[i] is not None:
            yield from rec(t[i])
```

But if a tree is very deep, recursion can become a problem. To remove recursion, we can handle our own stack—a list used in last-in, first-out (LIFO) fashion, thanks to its `append` and `pop` methods. To wit:

```
def norec(t):
    stack = [t]
    while stack:
        t = stack.pop()
        yield t[0]
        for i in (2, 1):
            if t[i] is not None:
                stack.append(t[i])
```

The only small issue to be careful about, to keep exactly the same order of **`yield`**s as `rec`, is switching the `(1, 2)` index order in which to examine descendants to `(2, 1)`, adjusting to the "reversed" (last-in, first-out) behavior of `stack`.



4
Object-Oriented Python

Python is an object-oriented (OO) programming language. Unlike some other object-oriented languages, however, Python doesn't force you to use the object-oriented paradigm exclusively: it also supports procedural programming, with modules and functions, so that you can select the best paradigm for each part of your program. The object-oriented paradigm helps you group state (data) and behavior (code) together in handy packets of functionality. Moreover, it offers some useful specialized mechanisms covered in this chapter, like *inheritance* and *special methods*. The simpler procedural approach, based on modules and functions, may be more suitable when you don't need the pluses[1] of object-oriented programming. With Python, you can mix and match paradigms.

In addition to core OO concepts, this chapter covers *abstract base classes*, *decorators*, and *metaclasses*.

Classes and Instances

If you're familiar with object-oriented programming in other OO languages such as C++ or Java, you probably have a good grasp of classes and instances: a *class* is a user-defined type, which you *instantiate* to build *instances*, i.e., objects of that type. Python supports this through its class and instance objects.

Python Classes

A *class* is a Python object with the following characteristics:

1 Or "drawbacks," according to one reviewer. One developer's meat is another developer's poison.

- You can call a class object just like you'd call a function. The call, known as *instantiation*, returns an object known as an *instance* of the class; the class is also known as the instance's *type*.
- A class has arbitrarily named attributes that you can bind and reference.
- The values of class attributes can be *descriptors* (including functions), covered in "Descriptors" on page 119, or ordinary data objects.
- Class attributes bound to functions are also known as *methods* of the class.
- A method can have any one of many Python-defined names with two leading and two trailing underscores (known as *dunder names*, short for "double-underscore names"—the name `__init__`, for example, is pronounced "dunder init"). Python implicitly calls such special methods, when a class supplies them, when various kinds of operations occur on that class or its instances.
- A class can *inherit* from one or more classes, meaning it delegates to other class objects the lookup of some attributes (including regular and dunder methods) that are not in the class itself.

An instance of a class is a Python object with arbitrarily named attributes that you can bind and reference. Every instance object delegates attribute lookup to its class for any attribute not found in the instance itself. The class, in turn, may delegate the lookup to classes from which it inherits, if any.

In Python, classes are objects (values), handled just like other objects. You can pass a class as an argument in a call to a function, and a function can return a class as the result of a call. You can bind a class to a variable, an item in a container, or an attribute of an object. Classes can also be keys into a dictionary. Since classes are perfectly ordinary objects in Python, we often say that classes are *first-class* objects.

The class Statement

The **`class`** statement is the most usual way you create a class object. **`class`** is a single-clause compound statement with the following syntax:

```
class Classname(base-classes, *, **kw):
    statement(s)
```

`Classname` is an identifier: a variable that the class statement, when finished, binds (or rebinds) to the just-created class object. Python naming conventions advise using title case for class names, such as `Item`, `PrivilegedUser`, `MultiUseFacility`, etc.

`base-classes` is a comma-delimited series of expressions whose values are class objects. Various programming languages use different names for these class objects: you can call them the *bases, superclasses*, or *parents* of the class. You can say the class created *inherits* from, *derives* from, *extends*, or *subclasses* its base classes; in this book, we generally use *extend*. This class is a *direct subclass* or *descendant* of its

base classes. `**kw` can include a named argument `metaclass=` to establish the class's *metaclass*,[2] as covered in "How Python Determines a Class's Metaclass" on page 160.

Syntactically, including *`base-classes`* is optional: to indicate that you're creating a class without bases, just omit *`base-classes`* (and, optionally, also omit the parentheses around it, placing the colon right after the class name). Every class inherits from `object`, whether you specify explicit bases or not.

The subclass relationship between classes is transitive: if *`C1`* extends *`C2`*, and *`C2`* extends *`C3`*, then *`C1`* extends *`C3`*. The built-in function `issubclass(C1, C2)` accepts two class objects: it returns **`True`** when *`C1`* extends *`C2`*, and otherwise it returns **`False`**. Any class is a subclass of itself; therefore, `issubclass(C, C)` returns **`True`** for any class *`C`*. We cover how base classes affect a class's functionality in "Inheritance" on page 129.

The nonempty sequence of indented statements that follows the **`class`** statement is the *class body*. A class body executes immediately as part of the **`class`** statement's execution. Until the body finishes executing, the new class object does not yet exist, and the *`Classname`* identifier is not yet bound (or rebound). "How a Metaclass Creates a Class" on page 160 provides more details about what happens when a **`class`** statement executes. Note that the **`class`** statement does not immediately create any instance of the new class, but rather defines the set of attributes shared by all instances when you later create instances by calling the class.

The Class Body

The body of a class is where you normally specify class attributes; these attributes can be descriptor objects (including functions) or ordinary data objects of any type. An attribute of a class can be another class—so, for example, you can have a **`class`** statement "nested" inside another **`class`** statement.

Attributes of class objects

You usually specify an attribute of a class object by binding a value to an identifier within the class body. For example:

```
class C1:
    x = 23
print(C1.x)                         # prints: 23
```

Here, the class object `C1` has an attribute named `x`, bound to the value `23`, and `C1.x` refers to that attribute. Such attributes may also be accessed via instances: `c = C1(); print(c.x)`. However, this isn't always reliable in practice. For example, when the class instance `c` has an `x` attribute, that's what `c.x` accesses, not the

2 When that's the case, it's also OK to have other named arguments after `metaclass=`. Such arguments, if any, are passed on to the metaclass.

class-level one. So, to access a class-level attribute from an instance, using, say, `print(c.__class__.x)` may be best.

You can also bind or unbind class attributes outside the class body. For example:

```
class C2:
    pass
C2.x = 23
print(C2.x)                        # prints: 23
```

Your program is usually more readable if you bind class attributes only with statements inside the class body. However, rebinding them elsewhere may be necessary if you want to carry state information at a class, rather than instance, level; Python lets you do that, if you wish. There is no difference between a class attribute bound in the class body and one bound or rebound outside the body by assigning to an attribute.

As we'll discuss shortly, all class instances share all of the class's attributes.

The **class** statement implicitly sets some class attributes. The attribute `__name__` is the *`Classname`* identifier string used in the **class** statement. The attribute `__bases__` is the tuple of class objects given (or implied) as the base classes in the **class** statement. For example, using the class `C1` we just created:

```
print(C1.__name__, C1.__bases__) # prints: C1 (<class 'object'>,)
```

A class also has an attribute called `__dict__`, which is the read-only mapping that the class uses to hold other attributes (also known, informally, as the class's *namespace*).

In statements directly in a class's body, references to class attributes must use a simple name, not a fully qualified name. For example:

```
class C3:
    x = 23
    y = x + 22                     # must use just x, not C3.x
```

However, in statements within *methods* defined in a class body, references to class attributes must use a fully qualified name, not a simple name. For example:

```
class C4:
    x = 23
    def amethod(self):
        print(C4.x)                # must use C4.x or self.x, not just x!
```

Attribute references (i.e., expressions like *`C.x`*) have semantics richer than attribute bindings. We cover such references in detail in "Attribute Reference Basics" on page 124.

Function definitions in a class body

Most class bodies include some **def** statements, since functions (known as *methods* in this context) are important attributes for most class instances. A **def** statement in a class body obeys the rules covered in "Functions" on page 93. In addition, a method defined in a class body has a mandatory first parameter, conventionally always named `self`, that refers to the instance on which you call the method. The `self` parameter plays a special role in method calls, as covered in "Bound and Unbound Methods" on page 126.

Here's an example of a class that includes a method definition:

```
class C5:
    def hello(self):
        print('Hello')
```

A class can define a variety of special dunder methods relating to specific operations on its instances. We discuss these methods in detail in "Special Methods" on page 141.

Class-private variables

When a statement in a class body (or in a method in the body) uses an identifier starting (but not ending) with two underscores, such as `__ident`, Python implicitly changes the identifier to `_Classname__ident`, where `Classname` is the name of the class. This implicit change lets a class use "private" names for attributes, methods, global variables, and other purposes, reducing the risk of accidentally duplicating names used elsewhere (particularly in subclasses).

By convention, identifiers starting with a *single* underscore are private to the scope that binds them, whether that scope is or isn't a class. The Python compiler does not enforce this privacy convention: it is up to programmers to respect it.

Class documentation strings

If the first statement in the class body is a string literal, the compiler binds that string as the *documentation string* (or *docstring*) for the class. The docstring for the class is available in the `__doc__` attribute; if the first statement in the class body is *not* a string literal, its value is **`None`**. See "Docstrings" on page 99 for more information on documentation strings.

Descriptors

A *descriptor* is an object whose class supplies one or more special methods named `__get__`, `__set__`, or `__delete__`. Descriptors that are class attributes control the semantics of accessing and setting attributes on instances of that class. Roughly speaking, when you access an instance attribute, Python gets the attribute's value by calling `__get__` on the corresponding descriptor, if any. For example:

```
class Const:  # class with an overriding descriptor, see later
    def __init__(self, value):
        self.__dict__['value'] = value
    def __set__(self, *_):
        # silently ignore any attempt at setting
```

```
        # (a better design choice might be to raise AttributeError)
        pass
    def __get__(self, *_):
        # always return the constant value
        return self.__dict__['value']
    def __delete__(self, *_):
        # silently ignore any attempt at deleting
        # (a better design choice might be to raise AttributeError)
        pass

class X:
    c = Const(23)

x = X()
print(x.c)  # prints: 23
x.c = 42    # silently ignored (unless you raise AttributeError)
print(x.c)  # prints: 23
del x.c     # silently ignored again (ditto)
print(x.c)  # prints: 23
```

For more details, see "Attribute Reference Basics" on page 124.

Overriding and nonoverriding descriptors

When a descriptor's class supplies a special method named `__set__`, the descriptor is known as an *overriding descriptor* (or, using the older, confusing terminology, a *data descriptor*); when the descriptor's class supplies `__get__` and not `__set__`, the descriptor is known as a *nonoverriding descriptor*.

For example, the class of function objects supplies `__get__`, but not `__set__`; therefore, function objects are nonoverriding descriptors. Roughly speaking, when you assign a value to an instance attribute with a corresponding descriptor that is overriding, Python sets the attribute value by calling `__set__` on the descriptor. For more details, see "Attributes of instance objects" on page 121.

The third dunder method of the descriptor protocol is `__delete__`, called when the **`del`** statement is used on the descriptor instance. If **`del`** is not supported, it is still a good idea to implement `__delete__`, raising a proper `AttributeError` exception; otherwise, the caller will get a mysterious `AttributeError: __delete__` exception.

The online docs include many more examples of descriptors and their related methods.

Instances

To create an instance of a class, call the class object as if it were a function. Each call returns a new instance whose type is that class:

```
an_instance = C5()
```

The built-in function `isinstance(`*`i`*`, `*`C`*`)`, with a class as argument *`C`*, returns **`True`** when *`i`* is an instance of class *`C`* or any subclass of *`C`*. Otherwise, `isinstance` returns

False. If *C* is a tuple of types (**3.10+** or multiple types joined using the | operator), `isinstance` returns **True** if *i* is an instance or subclass instance of any of the given types, and **False** otherwise.

__init__

When a class defines or inherits a method named `__init__`, calling the class object executes `__init__` on the new instance to perform per instance initialization. Arguments passed in the call must correspond to `__init__`'s parameters, except for the parameter `self`. For example, consider the following class definition:

```
class C6:
    def __init__(self, n):
        self.x = n
```

Here's how you can create an instance of the `C6` class:

```
another_instance = C6(42)
```

As shown in the `C6` class definition, the `__init__` method typically contains statements that bind instance attributes. An `__init__` method must not return a value other than **None**; if it does, Python raises a `TypeError` exception.

The main purpose of `__init__` is to bind, and thus create, the attributes of a newly created instance. You may also bind, rebind, or unbind instance attributes outside `__init__`. However, your code is more readable when you initially bind all class instance attributes in the `__init__` method.

When `__init__` is absent (and not inherited from any base class), you must call the class without arguments, and the new instance has no instance-specific attributes.

Attributes of instance objects

Once you have created an instance, you can access its attributes (data and methods) using the dot (`.`) operator. For example:

```
an_instance.hello()                    # prints: Hello
print(another_instance.x)              # prints: 42
```

Attribute references such as these have fairly rich semantics in Python; we cover them in detail in "Attribute Reference Basics" on page 124.

You can give an instance object an attribute by binding a value to an attribute reference. For example:

```
class C7:
    pass
z = C7()
z.x = 23
print(z.x)                             # prints: 23
```


Object-Oriented Python

Instance object z now has an attribute named x, bound to the value 23, and z.x refers to that attribute. The __setattr__ special method, if present, intercepts every attempt to bind an attribute. (We cover __setattr__ in Table 4-1.)

When you attempt to bind to an instance attribute whose name corresponds to an overriding descriptor in the class, the descriptor's __set__ method intercepts the attempt: if C7.x were an overriding descriptor, z.x=23 would execute type(z).x.__set__(z, 23).

Creating an instance sets two instance attributes. For any instance *z*, *z*.__class__ is the class object to which *z* belongs, and *z*.__dict__ is the mapping *z* uses to hold its other attributes. For example, for the instance z we just created:

```
print(z.__class__.__name__, z.__dict__)  # prints: C7 {'x':23}
```

You may rebind (but not unbind) either or both of these attributes, but this is rarely necessary.

For any instance *z*, any object *x*, and any identifier *S* (except __class__ and __dict__), *z*.*S*=*x* is equivalent to *z*.__dict__['*S*']=*x* (unless a __setattr__ special method, or an overriding descriptor's __set__ special method, intercepts the binding attempt). For example, again referring to the z we just created:

```
z.y = 45
z.__dict__['z'] = 67
print(z.x, z.y, z.z)                     # prints: 23 45 67
```

There is no difference between instance attributes created by assigning to attributes and those created by explicitly binding an entry in *z*.__dict__.

The factory function idiom

It's often necessary to create instances of different classes depending on some condition, or avoid creating a new instance if an existing one is available for reuse. A common misconception is that such needs might be met by having __init__ return a particular object. However, this approach is infeasible: Python raises an exception if __init__ returns any value other than **None**. The best way to implement flexible object creation is to use a function rather than calling the class object directly. A function used this way is known as a *factory function*.

Calling a factory function is a flexible approach: a function may return an existing reusable instance or create a new instance by calling whatever class is appropriate. Say you have two almost interchangeable classes, SpecialCase and NormalCase, and want to flexibly generate instances of either one of them, depending on an argument. The following appropriate_case factory function, as a "toy" example, allows you to do just that (we'll talk more about the self parameter in "Bound and Unbound Methods" on page 126):

```
class SpecialCase:
    def amethod(self):
        print('special')
```

```
class NormalCase:
    def amethod(self):
        print('normal')
def appropriate_case(isnormal=True):
    if isnormal:
        return NormalCase()
    else:
        return SpecialCase()
aninstance = appropriate_case(isnormal=False)
aninstance.amethod()                  # prints: special
```

__new__

Every class has (or inherits) a class method named `__new__` (we cover class methods in "Class methods" on page 135). When you call `C(*args, **kwds)` to create a new instance of class `C`, Python first calls `C.__new__(C, *args, **kwds)`, and uses `__new__`'s return value *x* as the newly created instance. Then Python calls `C.__init__(x, *args, **kwds)`, but only when *x* is indeed an instance of `C` or any of its subclasses (otherwise, *x*'s state remains as `__new__` had left it). Thus, for example, the statement `x=C(23)` is equivalent to:

```
x = C.__new__(C, 23)
if isinstance(x, C):
    type(x).__init__(x, 23)
```

`object.__new__` creates a new, uninitialized instance of the class it receives as its first argument. It ignores other arguments when that class has an `__init__` method, but it raises an exception when it receives other arguments beyond the first, and the class that's the first argument does not have an `__init__` method. When you override `__new__` within a class body, you do not need to add `__new__=classmethod(__new__)`, nor use an `@classmethod` decorator, as you normally would: Python recognizes the name `__new__` and treats it as special in this context. In those sporadic cases in which you rebind `C.__new__` later, outside the body of class `C`, you do need to use `C.__new__=classmethod(whatever)`.

`__new__` has most of the flexibility of a factory function, as covered in the previous section. `__new__` may choose to return an existing instance or make a new one, as appropriate. When `__new__` does create a new instance, it usually delegates creation to `object.__new__` or the `__new__` method of another superclass of `C`.

The following example shows how to override the class method `__new__` in order to implement a version of the Singleton design pattern:

```
class Singleton:
    _singletons = {}
    def __new__(cls, *args, **kwds):
        if cls not in cls._singletons:
            cls._singletons[cls] = obj = super().__new__(cls)
            obj._initialized = False
        return cls._singletons[cls]
```

(We cover the built-in super in "Cooperative superclass method calling" on page 132.)

Any subclass of Singleton (that does not further override __new__) has exactly one instance. When the subclass defines __init__, it must ensure __init__ is safe to call repeatedly (at each call of the subclass) on the subclass's only instance.[3] In this example, we insert the _initialized attribute, set to **False**, when __new__ actually creates a new instance. Subclasses' __init__ methods can test if self._initialized is **False** and, if so, set it to **True** and continue with the rest of the __init__ method. When subsequent "creates" of the singleton instance call __init__ again, self._initialized will be **True**, indicating the instance is already initialized, and __init__ can typically just return, avoiding some repetitive work.

Attribute Reference Basics

An *attribute reference* is an expression of the form *x.name*, where *x* is any expression and *name* is an identifier called the *attribute name*. Many Python objects have attributes, but an attribute reference has special, rich semantics when *x* refers to a class or instance. Methods are attributes, too, so everything we say about attributes in general also applies to callable attributes (i.e., methods).

Say that *x* is an instance of class C, which inherits from base class B. Both classes and the instance have several attributes (data and methods), as follows:

```
class B:
    a = 23
    b = 45
    def f(self):
        print('method f in class B')
    def g(self):
        print('method g in class B')
class C(B):
    b = 67
    c = 89
    d = 123
    def g(self):
        print('method g in class C')
    def h(self):
        print('method h in class C')
x = C()
x.d = 77
x.e = 88
```

A few attribute dunder names are special. *C*.__name__ is the string '*C*', the class's name. *C*.__bases__ is the tuple (*B*,), the tuple of *C*'s base classes. *x*.__class__ is

3 That need arises because __init__, on any subclass of Singleton that defines this special method, repeatedly executes, each time you instantiate the subclass, on the only instance that exists for each subclass of Singleton.

the class *C* to which *x* belongs. When you refer to an attribute with one of these special names, the attribute reference looks directly into a dedicated slot in the class or instance object and fetches the value it finds there. You cannot unbind these attributes. You may rebind them on the fly, changing the name or base classes of a class or the class of an instance, but this advanced technique is rarely necessary.

Class *C* and instance *x* each have one other special attribute: a mapping named `__dict__` (typically mutable for *x*, but not for *C*). All other attributes of a class or instance,[4] except the few special ones, are held as items in the `__dict__` attribute of the class or instance.

Getting an attribute from a class

When you use the syntax `C.name` to refer to an attribute on a class object *C*, lookup proceeds in two steps:

1. When `'name'` is a key in `C.__dict__`, `C.name` fetches the value *v* from `C.__dict__['name']`. Then, when *v* is a descriptor (i.e., `type(v)` supplies a method named `__get__`), the value of `C.name` is the result of calling `type(v).__get__(v, None, C)`. When *v* is not a descriptor, the value of `C.name` is *v*.
2. When `'name'` is *not* a key in `C.__dict__`, `C.name` delegates the lookup to *C*'s base classes, meaning it loops on *C*'s ancestor classes and tries the *name* lookup on each (in *method resolution order*, as covered in "Inheritance" on page 129).

Getting an attribute from an instance

When you use the syntax `x.name` to refer to an attribute of instance *x* of class *C*, lookup proceeds in three steps:

1. When `'name'` is in *C* (or in one of *C*'s ancestor classes) as the name of an overriding descriptor *v* (i.e., `type(v)` supplies methods `__get__` and `__set__`), the value of `x.name` is the result of `type(v).__get__(v, x, C)`.
2. Otherwise, when `'name'` is a key in `x.__dict__`, `x.name` fetches and returns the value at `x.__dict__['name']`.
3. Otherwise, `x.name` delegates the lookup to *x*'s class (according to the same two-step lookup process used for `C.name`, as just detailed):
   - When this finds a descriptor *v*, the overall result of the attribute lookup is, again, `type(v).__get__(v, x, C)`.
   - When this finds a nondescriptor value *v*, the overall result of the attribute lookup is just *v*.

4 Except for instances of a class defining `__slots__`, covered in "__slots__" on page 139.

When these lookup steps do not find an attribute, Python raises an `AttributeError` exception. However, for lookups of *`x.name`*, when *`C`* defines or inherits the special method `__getattr__`, Python calls *`C`*`.__getattr__(`*`x`*`, '`*`name`*`')` rather than raising the exception. It's then up to `__getattr__` to return a suitable value or raise the appropriate exception, normally `AttributeError`.

Consider the following attribute references, defined previously:

```
print(x.e, x.d, x.c, x.b, x.a)              # prints: 88 77 89 67 23
```

`x.e` and `x.d` succeed in step 2 of the instance lookup process, since no descriptors are involved and `'e'` and `'d'` are both keys in `x.__dict__`. Therefore, the lookups go no further but rather return `88` and `77`. The other three references must proceed to step 3 of the instance lookup process and look in `x.__class__` (i.e., `C`). `x.c` and `x.b` succeed in step 1 of the class lookup process, since `'c'` and `'b'` are both keys in `C.__dict__`. Therefore, the lookups go no further but rather return `89` and `67`. `x.a` gets all the way to step 2 of the class lookup process, looking in `C.__bases__[0]` (i.e., `B`). `'a'` is a key in `B.__dict__`; therefore, `x.a` finally succeeds and returns `23`.

Setting an attribute

Note that the attribute lookup steps happen as just described only when you *refer* to an attribute, not when you *bind* an attribute. When you bind to a class or instance attribute whose name is not special (unless a `__setattr__` method, or the `__set__` method of an overriding descriptor, intercepts the binding of an instance attribute), you affect only the `__dict__` entry for the attribute (in the class or instance, respectively). In other words, for attribute binding, there is no lookup procedure involved, except for the check for overriding descriptors.

Bound and Unbound Methods

The method `__get__` of a function object can return the function object itself, or a *bound method object* that wraps the function; a bound method is associated with the specific instance it's obtained from.

In the code in the previous section, the attributes `f`, `g`, and `h` are functions; therefore, an attribute reference to any one of them returns a method object that wraps the respective function. Consider the following:

```
print(x.h, x.g, x.f, C.h, C.g, C.f)
```

This statement outputs three bound methods, represented by strings like:

```
<bound method C.h of <__main__.C object at 0x8156d5c>>
```

and then three function objects, represented by strings like:

```
<function C.h at 0x102cabae8>
```

Bound Methods Versus Function Objects

We get bound methods when the attribute reference is on instance *x*, and function objects when the attribute reference is on class *C*.

Because a bound method is already associated with a specific instance, you can call the method as follows:

```
x.h()                   # prints: method h in class C
```

The key thing to notice here is that you don't pass the method's first argument, `self`, by the usual argument-passing syntax. Rather, a bound method of instance *x* implicitly binds the `self` parameter to object *x*. Thus, the method's body can access the instance's attributes as attributes of `self`, even though we don't pass an explicit argument to the method.

Let's take a closer look at bound methods. When an attribute reference on an instance, in the course of the lookup, finds a function object that's an attribute in the instance's class, the lookup calls the function's `__get__` method to get the attribute's value. The call, in this case, creates and returns a *bound method* that wraps the function.

Note that when the attribute reference's lookup finds a function object directly in *x*`.__dict__`, the attribute reference operation does *not* create a bound method. In such cases, Python does not treat the function as a descriptor and does not call the function's `__get__` method; rather, the function object itself is the attribute's value. Similarly, Python creates no bound methods for callables that are not ordinary functions, such as built-in (as opposed to Python-coded) functions, since such callables are not descriptors.

A bound method has three read-only attributes in addition to those of the function object it wraps: `im_class` is the class object that supplies the method, `im_func` is the wrapped function, and `im_self` refers to *x*, the instance from which you got the method.

You use a bound method just like its `im_func` function, but calls to a bound method do not explicitly supply an argument corresponding to the first parameter (conventionally named `self`). When you call a bound method, the bound method passes `im_self` as the first argument to `im_func` before other arguments (if any) given at the point of call.

Let's follow, in excruciatingly low-level detail, the conceptual steps involved in a method call with the normal syntax *x*`.`*name*`(`*arg*`)`. In the following context:

```
def f(a, b): ...              # a function f with two arguments

class C:
    name = f
x = C()
```

x is an instance object of class C, name is an identifier that names a method of x's (an attribute of C whose value is a function, in this case function f), and *arg* is any expression. Python first checks if 'name' is the attribute name in C of an overriding descriptor, but it isn't—functions are descriptors, because their type defines the method __get__, but *not* overriding ones, because their type does not define the method __set__. Python next checks if 'name' is a key in x._dict__, but it isn't. So, Python finds name in C (everything would work just the same if name were found, by inheritance, in one of C's __bases__). Python notices that the attribute's value, function object f, is a descriptor. Therefore, Python calls f.__get__(x, C), which returns a bound method object with im_func set to f, im_class set to C, and im_self set to x. Then Python calls this bound method object, with *arg* as the only argument. The bound method inserts im_self (i.e., x) as the first argument, and *arg* becomes the second one in a call to the bound method's im_func (i.e., function f). The overall effect is just like calling:

```
x.__class__.__dict__['name'](x, arg)
```

When a bound method's function body executes, it has no special namespace relationship to either its self object or any class. Variables referenced are local or global, just like any other function, as covered in "Namespaces" on page 105. Variables do not implicitly indicate attributes in self, nor do they indicate attributes in any class object. When the method needs to refer to, bind, or unbind an attribute of its self object, it does so by standard attribute reference syntax (e.g., self.*name*).[5] The lack of implicit scoping may take some getting used to (simply because Python differs in this respect from many, though far from all, other object-oriented languages), but it results in clarity, simplicity, and the removal of potential ambiguities.

Bound method objects are first-class objects: you can use them wherever you can use a callable object. Since a bound method holds references to both the function it wraps and the self object on which it executes, it's a powerful and flexible alternative to a closure (covered in "Nested functions and nested scopes" on page 107). An instance object whose class supplies the special method __call__ (covered in Table 4-1) offers another viable alternative. These constructs let you bundle some behavior (code) and some state (data) into a single callable object. Closures are simplest, but they are somewhat limited in their applicability. Here's the closure from the section on nested functions and nested scopes:

```
def make_adder_as_closure(augend):
    def add(addend, _augend=augend):
        return addend + _augend
    return add
```

Bound methods and callable instances are richer and more flexible than closures. Here's how to implement the same functionality with a bound method:

5 Some other OO languages, like Modula-3, similarly require explicit use of self.

```
def make_adder_as_bound_method(augend):
    class Adder:
        def __init__(self, augend):
            self.augend = augend
        def add(self, addend):
            return addend+self.augend
    return Adder(augend).add
```

And here's how to implement it with a callable instance (an instance whose class supplies the special method `__call__`):

```
def make_adder_as_callable_instance(augend):
    class Adder:
        def __init__(self, augend):
            self.augend = augend
        def __call__(self, addend):
            return addend+self.augend
    return Adder(augend)
```

From the viewpoint of the code that calls the functions, all of these factory functions are interchangeable, since all of them return callable objects that are polymorphic (i.e., usable in the same ways). In terms of implementation, the closure is simplest; the object-oriented approaches—i.e., the bound method and the callable instance—use more flexible, general, and powerful mechanisms, but there is no need for that extra power in this simple example (since no other state is required beyond the `augend`, which is just as easily carried in the closure as in either of the object-oriented approaches).

Inheritance

When you use an attribute reference *`C.name`* on a class object *`C`*, and `'name'` is not a key in *`C`*`.__dict__`, the lookup implicitly proceeds on each class object that is in *`C`*`.__bases__` in a specific order (which for historical reasons is known as the *method resolution order*, or MRO, but in fact applies to all attributes, not just methods). *C*'s base classes may in turn have their own bases. The lookup checks direct and indirect ancestors, one by one, in MRO, stopping when `'name'` is found.

Method resolution order

The lookup of an attribute name in a class essentially occurs by visiting ancestor classes in left-to-right, depth-first order. However, in the presence of multiple inheritance (which makes the inheritance graph a general *directed acyclic graph*, or DAG, rather than specifically a tree), this simple approach might lead to some ancestor classes being visited twice. In such cases, the resolution order leaves in the lookup sequence only the *rightmost* occurrence of any given class.

Each class and built-in type has a special read-only class attribute called `__mro__`, which is the tuple of types used for method resolution, in order. You can reference `__mro__` only on classes, not on instances, and, since `__mro__` is a read-only attribute, you cannot rebind or unbind it. For a detailed and highly technical explanation of all aspects of Python's MRO, you may want to study Michele Simionato's essay "The Python 2.3 Method Resolution Order"[6] and Guido van Rossum's article on "The History of Python". In particular, note that it *is* quite possible that Python cannot determine *any* unambiguous MRO for a certain class: in this case, Python raises a `TypeError` exception when it executes that **`class`** statement.

Overriding attributes

As we've just seen, the search for an attribute proceeds along the MRO (typically, up the inheritance tree) and stops as soon as the attribute is found. Descendant classes are always examined before their ancestors, so that when a subclass defines an attribute with the same name as one in a superclass, the search finds the definition in the subclass and stops there. This is known as the subclass *overriding* the definition in the superclass. Consider the following code:

```
class B:
    a = 23
    b = 45
    def f(self):
        print('method f in class B')
    def g(self):
        print('method g in class B')
class C(B):
    b = 67
    c = 89
    d = 123
    def g(self):
        print('method g in class C')
    def h(self):
        print('method h in class C')
```

Here, class `C` overrides attributes `b` and `g` of its superclass `B`. Note that, unlike in some other languages, in Python you may override data attributes just as easily as callable attributes (methods).

Delegating to superclass methods

When subclass *`C`* overrides a method *`f`* of its superclass *`B`*, the body of *`C.f`* often wants to delegate some part of its operation to the superclass's implementation of the method. This can sometimes be done using a function object, as follows:

```
class Base:
    def greet(self, name):
        print('Welcome', name)
class Sub(Base):
    def greet(self, name):
        print('Well Met and', end=' ')
        Base.greet(self, name)
```

6 Many Python releases later, Michele's essay still applies!

```python
x = Sub()
x.greet('Alex')
```

The delegation to the superclass, in the body of `Sub.greet`, uses a function object obtained by attribute reference `Base.greet` on the superclass, and therefore passes all arguments normally, including `self`. (If it seems a bit ugly explicitly using the base class, bear with us; you'll see a better way to do this shortly, in this very section). Delegating to a superclass implementation is a frequent use of such function objects.

One common use of delegation occurs with the special method `__init__`. When Python creates an instance, it does not automatically call the `__init__` methods of any base classes, unlike some other object-oriented languages. It is up to a subclass to initialize its superclasses, using delegation as necessary. For example:

```python
class Base:
    def __init__(self):
        self.anattribute = 23
class Derived(Base):
    def __init__(self):
        Base.__init__(self)
        self.anotherattribute = 45
```


If the `__init__` method of class `Derived` didn't explicitly call that of class `Base`, instances of `Derived` would miss that portion of their initialization. Thus, such instances would violate the Liskov substitution principle (LSP), since they'd lack the attribute `anattribute`. This issue does *not* arise if a subclass does not define `__init__`, since in that case it inherits it from the superclass. So, there is *never* any reason to code:

```python
class Derived(Base):
    def __init__(self):
        Base.__init__(self)
```

Never Code a Method That Just Delegates to the Superclass

You should never define a semantically empty `__init__` (i.e., one that just delegates to the superclass). Instead, inherit `__init__` from the superclass. This advice applies to *all* methods, special or not, but for some reason the bad habit of coding such semantically empty methods seems to show up most often for `__init__`.

The preceding code illustrates the concept of delegation to an object's superclass, but it is actually a poor practice, in today's Python, to code these superclasses explicitly by name. If the base class is renamed, all the call sites to it must be updated. Or, worse, if refactoring the class hierarchy introduces a new layer between the `Derived` and `Base` class, the newly inserted class's method will be silently skipped.

The recommended approach is to call methods defined in a superclass using the `super` built-in type. To invoke methods up the inheritance chain, just call `super()`, without arguments:

```
class Derived(Base):
    def __init__(self):
        super().__init__()
        self.anotherattribute = 45
```

Cooperative superclass method calling

Explicitly calling the superclass's version of a method using the superclass's name is also quite problematic in cases of multiple inheritance with so-called "diamond-shaped" graphs. Consider the following code:

```
class A:
    def met(self):
        print('A.met')
class B(A):
    def met(self):
        print('B.met')
        A.met(self)
class C(A):
    def met(self):
        print('C.met')
        A.met(self)
class D(B,C):
    def met(self):
        print('D.met')
        B.met(self)
        C.met(self)
```

When we call `D().met()`, `A.met` ends up being called twice. How can we ensure that each ancestor's implementation of the method is called once and only once? The solution is to use `super`:

```
class A:
    def met(self):
        print('A.met')
class B(A):
    def met(self):
        print('B.met')
        super().met()
class C(A):
    def met(self):
        print('C.met')
        super().met()
class D(B,C):
    def met(self):
        print('D.met')
        super().met()
```

Now, `D().met()` results in exactly one call to each class's version of `met`. If you get into the good habit of always coding superclass calls with `super`, your classes will fit smoothly even in complicated inheritance structures—and there will be no ill effects if the inheritance structure instead turns out to be simple.

The only situation in which you may prefer to use the rougher approach of calling superclass methods through the explicit syntax is when various classes have different and incompatible signatures for the same method. This is an unpleasant situation in many respects; if you do have to deal with it, the explicit syntax may sometimes be the least of the evils. Proper use of multiple inheritance is seriously hampered; but then, even the most fundamental properties of OOP, such as polymorphism between base and subclass instances, are impaired when you give methods of the same name different signatures in a superclass and its subclass.

Dynamic class definition using the type built-in function

In addition to the `type(obj)` use, you can also call `type` with three arguments to define a new class:

```
NewClass = type(name, bases, class_attributes, **kwargs)
```

where *`name`* is the name of the new class (which should match the target variable), *`bases`* is a tuple of immediate superclasses, *`class_attributes`* is a `dict` of class-level methods and attributes to define in the new class, and `**`*`kwargs`* are optional named arguments to pass to the metaclass of one of the base classes.

For example, with a simple hierarchy of `Vehicle` classes (such as `LandVehicle`, `WaterVehicle`, `AirVehicle`, `SpaceVehicle`, etc.), you can dynamically create hybrid classes at runtime, such as:

```
AmphibiousVehicle = type('AmphibiousVehicle',
                         (LandVehicle, WaterVehicle), {})
```

This would be equivalent to defining a multiply inherited class:

```
class AmphibiousVehicle(LandVehicle, WaterVehicle): pass
```

When you call type to create classes at runtime, you do not need to manually define the combinatorial expansion of all combinations of `Vehicle` subclasses, and adding new subclasses does not require massive extension of defined mixed classes.[7] For more notes and examples, see the online documentation.

"Deleting" class attributes

Inheritance and overriding provide a simple and effective way to add or modify (override) class attributes (such as methods) noninvasively—i.e., without modifying the base class defining the attributes—by adding or overriding the attributes in

7 One of the authors has used this technique to dynamically combine small mixin test classes to create complex test case classes to test multiple independent product features.

subclasses. However, inheritance does not offer a way to delete (hide) base classes' attributes noninvasively. If the subclass simply fails to define (override) an attribute, Python finds the base class's definition. If you need to perform such deletion, possibilities include the following:

- Override the method and raise an exception in the method's body.
- Eschew inheritance, hold the attributes elsewhere than in the subclass's `__dict__`, and define `__getattr__` for selective delegation.
- Override `__getattribute__` to similar effect.

The last of these techniques is demonstrated in "__getattribute__" on page 140.

Consider Using Aggregation Instead of Inheritance

An alternative to inheritance is to use *aggregation*: instead of inheriting from a base class, hold an instance of that base class as a private attribute. You then get complete control over the attribute's life cycle and public interface by providing public methods in the containing class that delegate to the contained attribute (i.e., by calling equivalent methods on the attribute). This way, the containing class has more control over the creation and deletion of the attribute; also, for any unwanted methods that the attribute's class provides, you simply don't write delegating methods in the containing class.

The Built-in object Type

The built-in `object` type is the ancestor of all built-in types and classes. The `object` type defines some special methods (documented in "Special Methods" on page 141) that implement the default semantics of objects:

`__new__`, `__init__`
: You can create a direct instance of `object` by calling `object()` without any arguments. The call uses `object.__new__` and `object.__init__` to make and return an instance object without attributes (and without even a `__dict__` in which to hold attributes). Such instance objects may be useful as "sentinels," guaranteed to compare unequal to any other distinct object.

`__delattr__`, `__getattr__`, `__getattribute__`, `__setattr__`
: By default, any object handles attribute references (as covered in "Attribute Reference Basics" on page 124) using these methods of `object`.

`__hash__`, `__repr__`, `__str__`
: Passing an object to `hash`, `repr`, or `str` calls the object's corresponding dunder method.

A subclass of `object` (i.e., any class) may—and often will!—override any of these methods and/or add others.

Class-Level Methods

Python supplies two built-in nonoverriding descriptor types, which give a class two distinct kinds of "class-level methods": *static methods* and *class methods*.

Static methods

A *static method* is a method that you can call on a class, or on any instance of the class, without the special behavior and constraints of ordinary methods regarding the first parameter. A static method may have any signature; it may have no parameters, and the first parameter, if any, plays no special role. You can think of a static method as an ordinary function that you're able to call normally, despite the fact that it happens to be bound to a class attribute.

While it is never *necessary* to define static methods (you can always choose to instead define a normal function, outside the class), some programmers consider them to be an elegant syntax alternative when a function's purpose is tightly bound to some specific class.

Object-Oriented Python

To build a static method, call the built-in type `staticmethod` and bind its result to a class attribute. Like all binding of class attributes, this is normally done in the body of the class, but you may also choose to perform it elsewhere. The only argument to `staticmethod` is the function to call when Python calls the static method. The following example shows one way to define and call a static method:

```
class AClass:
    def astatic():
        print('a static method')
    astatic = staticmethod(astatic)

an_instance = AClass()
print(AClass.astatic())              # prints: a static method
print(an_instance.astatic())         # prints: a static method
```

This example uses the same name for the function passed to `staticmethod` and for the attribute bound to `staticmethod`'s result. This naming convention is not mandatory, but it's a good idea, and we recommend you always use it. Python offers a special, simplified syntax to support this style, covered in "Decorators" on page 157.

Class methods

A *class method* is a method you can call on a class or on any instance of the class. Python binds the method's first parameter to the class on which you call the method, or the class of the instance on which you call the method; it does not bind it to the instance, as for normal bound methods. The first parameter of a class method is conventionally named `cls`.

As with static methods, while it is never *necessary* to define class methods (you can always choose to define a normal function, outside the class, that takes the class object as its first parameter), class methods are an elegant alternative to such functions (particularly since they can usefully be overridden in subclasses, when that is necessary).

To build a class method, call the built-in type `classmethod` and bind its result to a class attribute. Like all binding of class attributes, this is normally done in the body of the class, but you may choose to perform it elsewhere. The only argument to `classmethod` is the function to call when Python calls the class method. Here's one way you can define and call a class method:

```
class ABase:
    def aclassmet(cls):
        print('a class method for', cls.__name__)
    aclassmet = classmethod(aclassmet)
class ADeriv(ABase):
    pass

b_instance = ABase()
d_instance = ADeriv()
print(ABase.aclassmet())        # prints: a class method for ABase
print(b_instance.aclassmet())   # prints: a class method for ABase
print(ADeriv.aclassmet())       # prints: a class method for ADeriv
print(d_instance.aclassmet())   # prints: a class method for ADeriv
```

This example uses the same name for the function passed to `classmethod` and for the attribute bound to `classmethod`'s result. Again, this naming convention is not mandatory, but it's a good idea, and we recommend that you always use it. Python's simplified syntax to support this style is covered in "Decorators" on page 157.

Properties

Python supplies a built-in overriding descriptor type, usable to give a class's instances *properties*. A property is an instance attribute with special functionality. You reference, bind, or unbind the attribute with the normal syntax (e.g., `print(x.prop)`, `x.prop=23`, `del x.prop`). However, rather than following the usual semantics for attribute reference, binding, and unbinding, these accesses call on instance *x* the methods that you specify as arguments to the built-in type `property`. Here's one way to define a read-only property:

```
class Rectangle:
    def __init__(self, width, height):
        self.width = width
        self.height = height
    def area(self):
        return self.width * self.height
    area = property(area, doc='area of the rectangle')
```

Each instance *r* of class `Rectangle` has a synthetic read-only attribute `r.area`, which the method `r.area()` computes on the fly by multiplying the sides. The docstring `Rectangle.area.__doc__` is `'area of the rectangle'`. The `r.area` attribute is read-only (attempts to rebind or unbind it fail) because we specify only a get method in the call to property, and no set or del methods.

Properties perform tasks similar to those of the special methods __getattr__, __setattr__, and __delattr__ (covered in "General-Purpose Special Methods" on page 142), but properties are faster and simpler. To build a property, call the built-in type property and bind its result to a class attribute. Like all binding of class attributes, this is normally done in the body of the class, but you may choose to do it elsewhere. Within the body of a class *C*, you can use the following syntax:

```
attrib = property(fget=None, fset=None, fdel=None, doc=None)
```

When *x* is an instance of *C* and you reference *x.attrib*, Python calls on *x* the method you passed as argument fget to the property constructor, without arguments. When you assign *x.attrib* = *value*, Python calls the method you passed as argument fset, with *value* as the only argument. When you execute **del** *x.attrib*, Python calls the method you passed as argument fdel, without arguments. Python uses the argument you passed as doc as the docstring of the attribute. All parameters to property are optional. When an argument is missing, Python raises an exception when some code attempts that operation. For example, in the Rectangle example, we made the property area read-only because we passed an argument only for the parameter fget, and not for the parameters fset and fdel.

Object-Oriented Python

An elegant syntax to create properties in a class is to use property as a *decorator* (see "Decorators" on page 157):

```
class Rectangle:
    def __init__(self, width, height):
        self.width = width
        self.height = height
    @property
    def area(self):
        """area of the rectangle"""
        return self.width * self.height
```

To use this syntax, you *must* give the getter method the same name as you want the property to have; the method's docstring becomes the docstring of the property. If you want to add a setter and/or a deleter as well, use decorators named (in this example) area.setter and area.deleter, and name the methods thus decorated the same as the property, too. For example:

```
import math
class Rectangle:
    def __init__(self, width, height):
        self.width = width
        self.height = height
    @property
    def area(self):
        """area of the rectangle"""
        return self.width * self.height
    @area.setter
```

```python
    def area(self, value):
        scale = math.sqrt(value/self.area)
        self.width *= scale
        self.height *= scale
```

Why properties are important

The crucial importance of properties is that their existence makes it perfectly safe (and indeed advisable) for you to expose public data attributes as part of your class's public interface. Should it ever become necessary, in future versions of your class or other classes that need to be polymorphic to it, to have some code execute when the attribute is referenced, rebound, or unbound, you will be able to change the plain attribute into a property and get the desired effect without any impact on any code that uses your class (aka "client code"). This lets you avoid goofy idioms, such as *accessor* and *mutator* methods, required by OO languages lacking properties. For example, client code can use natural idioms like this:

```python
some_instance.widget_count += 1
```

rather than being forced into contorted nests of accessors and mutators like this:

```python
some_instance.set_widget_count(some_instance.get_widget_count() + 1)
```

If you're ever tempted to code methods whose natural names are something like `get_`*`this`* or `set_`*`that`*, wrap those methods into properties instead, for clarity.

Properties and inheritance

Inheritance of properties works just like for any other attribute. However, there's a little trap for the unwary: *the methods called upon to access a property are those defined in the class in which the property itself is defined*, without intrinsic use of further overriding that may happen in subclasses. Consider this example:

```python
class B:
    def f(self):
        return 23
    g = property(f)
class C(B):
    def f(self):
        return 42

c = C()
print(c.g)                # prints: 23, not 42
```

Accessing the property `c.g` calls `B.f`, not `C.f`, as you might expect. The reason is quite simple: the property constructor receives (directly or via the decorator syntax) the *function object* `f` (and that happens at the time the **`class`** statement for `B` executes, so the function object in question is the one also known as `B.f`). The fact that the subclass `C` later redefines the name `f` is therefore irrelevant, since the property performs no lookup for that name, but rather uses the function object it received at creation time. If you need to work around this issue, you can do it by adding the extra level of lookup indirection yourself:

```
class B:
    def f(self):
        return 23
    def _f_getter(self):
        return self.f()
    g = property(_f_getter)
class C(B):
    def f(self):
        return 42

c = C()
print(c.g)                # prints: 42, as expected
```

Here, the function object held by the property is `B._f_getter`, which in turn does perform a lookup for the name `f` (since it calls `self.f()`); therefore, the overriding of `f` has the expected effect. As David Wheeler famously put it, "All problems in computer science can be solved by another level of indirection."[8]

__slots__

Normally, each instance object *x* of any class *C* has a dictionary *x*.`__dict__` that Python uses to let you bind arbitrary attributes on *x*. To save a little memory (at the cost of letting *x* have only a predefined set of attribute names), you can define in class *C* a class attribute named `__slots__`, a sequence (normally a tuple) of strings (normally identifiers). When class *C* has `__slots__`, instance *x* of class *C* has no `__dict__`: trying to bind on *x* an attribute whose name is not in *C*.`__slots__` raises an exception.

Using `__slots__` lets you reduce memory consumption for small instance objects that can do without the powerful and convenient ability to have arbitrarily named attributes. `__slots__` is worth adding only to classes that can have so many instances that saving a few tens of bytes per instance is important—typically classes that could have millions, not mere thousands, of instances alive at the same time. Unlike most other class attributes, however, `__slots__` works as we've just described only if an assignment in the class body binds it as a class attribute. Any later alteration, rebinding, or unbinding of `__slots__` has no effect, nor does inheriting `__slots__` from a base class. Here's how to add `__slots__` to the `Rectangle` class defined earlier to get smaller (though less flexible) instances:

```
class OptimizedRectangle(Rectangle):
    __slots__ = 'width', 'height'
```

8 To complete the usually truncated famous quote: "except of course for the problem of too many indirections."

Object-Oriented Python

There's no need to define a slot for the `area` property: `__slots__` does not constrain properties, only ordinary instance attributes, which would reside in the instance's `__dict__` if `__slots__` wasn't defined.

3.8+ `__slots__` attributes can also be defined using a `dict` with attribute names for the keys and docstrings for the values. `OptimizedRectangle` could be declared more fully as:

```
class OptimizedRectangle(Rectangle):
    __slots__ = {'width': 'rectangle width in pixels',
                 'height': 'rectangle height in pixels'}
```

__getattribute__

All references to instance attributes go through the special method `__getattribute__`. This method comes from `object`, where it implements attribute reference semantics (as documented in "Attribute Reference Basics" on page 124). You may override `__getattribute__` for purposes such as hiding inherited class attributes for a subclass's instances. For instance, the following example shows one way to implement a list without `append`:

```
class listNoAppend(list):
    def __getattribute__(self, name):
        if name == 'append':
            raise AttributeError(name)
        return list.__getattribute__(self, name)
```

An instance *x* of class `listNoAppend` is almost indistinguishable from a built-in list object, except that its runtime performance is substantially worse, and any reference to `x.append` raises an exception.

Implementing `__getattribute__` can be tricky; it is often easier to use the built-in functions `getattr` and `setattr` and the instance's `__dict__` (if any), or to reimplement `__getattr__` and `__setattr__`. Of course, in some cases (such as the preceding example), there is no alternative.

Per Instance Methods

An instance can have instance-specific bindings for all attributes, including callable attributes (methods). For a method, just like for any other attribute (except those bound to overriding descriptors), an instance-specific binding hides a class-level binding: attribute lookup does not consider the class when it finds a binding directly in the instance. An instance-specific binding for a callable attribute does not perform any of the transformations detailed in "Bound and Unbound Methods" on page 126: the attribute reference returns exactly the same callable object that was earlier bound directly to the instance attribute.

However, this does not work as you might expect for per instance bindings of the special methods that Python calls implicitly as a result of various operations, as covered in "Special Methods" on page 141. Such implicit uses of special methods always rely on the *class-level* binding of the special method, if any. For example:

```
def fake_get_item(idx):
    return idx
class MyClass:
    pass
n = MyClass()
n.__getitem__ = fake_get_item
print(n[23])                      # results in:
# Traceback (most recent call last):
#   File "<stdin>", line 1, in ?
# TypeError: unindexable object
```

Inheritance from Built-in Types

A class can inherit from a built-in type. However, a class may directly or indirectly extend multiple built-in types only if those types are specifically designed to allow this level of mutual compatibility. Python does not support unconstrained inheritance from multiple arbitrary built-in types. Normally, a new-style class only extends at most one substantial built-in type. For example, this:

```
class noway(dict, list):
    pass
```

raises a `TypeError` exception, with a detailed explanation of "multiple bases have instance lay-out conflict." When you see such error messages, it means that you're trying to inherit, directly or indirectly, from multiple built-in types that are not specifically designed to cooperate at such a deep level.

Special Methods

A class may define or inherit special methods, often referred to as "dunder" methods because, as described earlier, their names have leading and trailing double underscores. Each special method relates to a specific operation. Python implicitly calls a special method whenever you perform the related operation on an instance object. In most cases, the method's return value is the operation's result, and attempting an operation when its related method is not present raises an exception.

Throughout this section, we point out the cases in which these general rules do not apply. In the following discussion, *`x`* is the instance of class *`C`* on which you perform the operation, and *`y`* is the other operand, if any. The parameter `self` of each method also refers to the instance object *`x`*. Whenever we mention calls to *`x`*`.`*`__whatever__`*`(...)`, keep in mind that the exact call happening is rather, pedantically speaking, *`x`*`.__class__.`*`__whatever__`*`(`*`x`*`, ...)`.

General-Purpose Special Methods

Some dunder methods relate to general-purpose operations. A class that defines or inherits these methods allows its instances to control such operations. These operations can be divided into categories:

Initialization and finalization
: A class can control its instances' initialization (a very common requirement) via special methods `__new__` and `__init__`, and/or their finalization (a rare requirement) via `__del__`.

String representation
: A class can control how Python renders its instances as strings via special methods `__repr__`, `__str__`, `__format__`, and `__bytes__`.

Comparison, hashing, and use in a Boolean context
: A class can control how its instances compare with other objects (via special methods `__lt__`, `__le__`, `__gt__`, `__ge__`, `__eq__`, and `__ne__`), how dictionaries use them as keys and sets use them as members (via `__hash__`), and whether they evaluate as truthy or falsy in Boolean contexts (via`__bool__`).

Attribute reference, binding, and unbinding
: A class can control access to its instances' attributes (reference, binding, unbinding) via special methods `__getattribute__`, `__getattr__`, `__setattr__`, and `__delattr__`.

Callable instances
: A class can make its instances callable, just like function objects, via special method `__call__`.

Table 4-1 documents the general-purpose special methods.

Table 4-1. General-purpose special methods

`__bool__`	`__bool__(self)` When evaluating *x* as true or false (see "Boolean Values" on page 51)—for example, on a call to `bool(x)`—Python calls `x.__bool__()`, which should return **`True`** or **`False`**. When `__bool__` is not present, Python calls `__len__`, and takes *x* as falsy when `x.__len__()` returns `0` (to check that a container is nonempty, avoid coding **`if`** `len(container)>0:`; use **`if`** `container:` instead). When neither `__bool__` nor `__len__` is present, Python considers *x* truthy.
`__bytes__`	`__bytes__(self)` Calling `bytes(x)` calls `x.__bytes__()`, if present. If a class supplies both special methods `__bytes__` and `__str__`, they should return "equivalent" strings, respectively, of `bytes` and `str` type.

`__call__`	`__call__(self[, args...])` When you call `x([args...])`, Python translates the operation into a call to `x.__call__([args...])`. The arguments for the call operation correspond to the parameters for the `__call__` method, minus the first one. The first parameter, conventionally called `self`, refers to *x*: Python supplies it implicitly, just as in any other call to a bound method.
`__del__`	`__del__(self)` Just before *x* disappears via garbage collection, Python calls `x.__del__()` to let *x* finalize itself. If `__del__` is absent, Python does no special finalization on garbage-collecting *x* (this is the most common case: very few classes need to define `__del__`). Python ignores the return value of `__del__` and doesn't implicitly call `__del__` methods of class *C*'s superclasses. *C*.`__del__` must explicitly perform any needed finalization, including, if need be, by delegation. When class *C* has base classes to finalize, *C*.`__del__` must call `super().__del__()`. The `__del__` method has no specific connection with the **`del`** statement, covered in "del Statements" on page 56. `__del__` is generally not the best approach when you need timely and guaranteed finalization. For such needs, use the **`try/finally`** statement covered in "try/finally" on page 198 (or, even better, the **`with`** statement, covered in "The with Statement" on page 93). Instances of classes defining `__del__` don't participate in cyclic garbage collection, covered in "Garbage Collection" on page 435. Be careful to avoid reference loops involving such instances: define `__del__` only when there is no feasible alternative.
`__delattr__`	`__delattr__(self, name)` At every request to unbind attribute `x.y` (typically, **`del`** `x.y`), Python calls `x.__delattr__('y')`. All the considerations discussed later for `__setattr__` also apply to `__delattr__`. Python ignores the return value of `__delattr__`. Absent `__delattr__`, Python turns **`del`** `x.y` into **`del`** `x.__dict__['y']`.
`__dir__`	`__dir__(self)` When you call `dir(x)`, Python translates the operation into a call to `x.__dir__()`, which must return a sorted list of *x*'s attributes. When *x*'s class has no `__dir__`, `dir(x)` performs introspection to return a sorted list of *x*'s attributes, striving to produce relevant, rather than complete, information.

Object-Oriented Python

`__eq__`, `__ge__`, `__gt__`, `__le__`, `__lt__`, `__ne__`	`__eq__(self, *other*)`, `__ge__(self, *other*)`, `__gt__(self, *other*)`, `__le__(self, *other*)`, `__lt__(self, *other*)`, `__ne__(self, *other*)` The comparisons *x* == *y*, *x* >= *y*, *x* > *y*, *x* <= *y*, *x* < *y*, and *x* != *y*, respectively, call the special methods listed here, which should return **`False`** or **`True`**. Each method may return `NotImplemented` to tell Python to handle the comparison in alternative ways (e.g., Python may then try *y* > *x* in lieu of *x* < *y*). Best practice is to define only one inequality comparison method (normally `__lt__`) plus `__eq__`, and decorate the class with `functools.total_ordering` (covered in Table 8-7), to avoid boilerplate and any risk of logical contradictions in your comparisons.
`__format__`	`__format__(self, format_string='')` Calling `format(*x*)` calls `*x*.__format__('')`, and calling `format(*x*, *format_string*)` calls `*x*.__format__(*format_string*)`. The class is responsible for interpreting the format string (each class may define its own small "language" of format specifications, inspired by those implemented by built-in types, as covered in "String Formatting" on page 287). When `__format__` is inherited from `object`, it delegates to `__str__` and does not accept a nonempty format string.
`__getattr__`	`__getattr__(self, *name*)` When *x*.*y* can't be found by the usual steps (i.e., when an `AttributeError` would usually be raised), Python calls `*x*.__getattr__('*y*')`. Python does not call `__getattr__` for attributes found by normal means (as keys in `*x*.__dict__`, or via `*x*.__class__`). If you want Python to call `__getattr__` for *every* attribute, keep the attributes elsewhere (e.g., in another `dict` referenced by an attribute with a private name), or override `__getattribute__` instead. `__getattr__` should raise `AttributeError` if it can't find *y*.

`__getattribute__`	`__getattribute_(self, name)` At every request to access attribute *x.y*, Python calls `x.__getattribute__('y')`, which must get and return the attribute value or else raise `AttributeError`. The usual semantics of attribute access (`x.__dict__`, `C.__slots__`, *C*'s class attributes, `x.__getattr__`) are all due to `object.__getattribute__`. When class *C* overrides `__getattribute__`, it must implement all of the attribute semantics it wants to offer. The typical way to implement attribute access is by delegating (e.g., call `object.__getattribute__(self, ...)` as part of the operation of your override of `__getattribute__`). **Overriding `__getattribute__` Slows Attribute Access** When a class overrides `__getattribute__`, all attribute accesses on instances of the class become slow, as the overriding code executes on every attribute access.
`__hash__`	`__hash__(self)` Calling `hash(x)` calls `x.__hash__()` (and so do other contexts that need to know *x*'s hash value, namely using *x* as a dictionary key, such as *D*`[x]` where *D* is a dictionary, or using *x* as a set member). `__hash__` must return an `int` such that *x*==*y* implies `hash(x)==hash(y)`, and must always return the same value for a given object. When `__hash__` is absent, calling `hash(x)` calls `id(x)` instead, as long as `__eq__` is also absent. Other contexts that need to know *x*'s hash value behave the same way. Any *x* such that `hash(x)` returns a result, rather than raising an exception, is known as a *hashable object*. When `__hash__` is absent, but `__eq__` is present, calling `hash(x)` raises an exception (and so do other contexts that need to know *x*'s hash value). In this case, *x* is not hashable and therefore cannot be a dictionary key or set member. You normally define `__hash__` only for immutable objects that also define `__eq__`. Note that if there exists any *y* such that *x*==*y*, even if *y* is of a different type, and both *x* and *y* are hashable, you *must* ensure that `hash(x)==hash(y)`. (There are few cases, among Python built-ins, where *x*==*y* can hold between objects of different types. The most important ones are equality between different number types: an `int` can equal a `bool`, a `float`, a `fractions.Fraction` instance, or a `decimal.Decimal` instance.)

`__init__`	`__init__(self[, *args*...])` When a call *C*`([`*args*`...])` creates instance *x* of class *C*, Python calls *x*`.__init__([`*args*`...])` to let *x* initialize itself. If `__init__` is absent (i.e., it's inherited from `object`), you must call *C* without arguments, *C*`()`, and *x* has no instance-specific attributes on creation. Python performs no implicit call to `__init__` methods of class *C*'s superclasses. *C*`.__init__` must explicitly perform any initialization, including, if need be, by delegation. For example, when class *C* has a base class *B* to initialize without arguments, the code in *C*.`__init__` must explicitly call `super().__init__()`. `__init__`'s inheritance works just like for any other method or attribute: if *C* itself does not override `__init__`, it inherits it from the first superclass in its `__mro__` to override `__init__`, like every other attribute. `__init__` must return `None`; otherwise, calling the class raises `TypeError`.
`__new__`	`__new__(cls[, *args*...])` When you call *C*`([`*args*`...])`, Python gets the new instance *x* that you are creating by invoking *C*`.__new__(`*C*`[, `*args*`...])`. Every class has the class method `__new__` (usually, it just inherits it from `object`), which can return any value *x*. In other words, `__new__` need not return a new instance of *C*, although it's expected to do so. If the value *x* that `__new__` returns is an instance of *C* or of any subclass of *C* (whether a new or a previously existing one), Python then calls `__init__` on *x* (with the same `[`*args*`...]` originally passed to `__new__`). **Initialize Immutables in __new__, All Others in __init__** You can perform most kinds of initialization of new instances in either `__init__` or `__new__`, so you may wonder where it's best to place them. Best practice is to put the initialization in `__init__` only, unless you have a specific reason to put it in `__new__`. (When a type is immutable, `__init__` cannot change its instances: in this case, `__new__` has to perform all initialization.)
`__repr__`	`__repr__(self)` Calling `repr(`*x*`)` (which happens implicitly in the interactive interpreter when *x* is the result of an expression statement) calls *x*`.__repr__()` to get and return a complete string representation of *x*. If `__repr__` is absent, Python uses a default string representation. `__repr__` should return a string with unambiguous information on *x*. When feasible, try to make `eval(repr(`*x*`))==`*x* (but, don't go crazy to achieve this goal!).

`__setattr__`	`__setattr__(self, name, value)` At any request to bind attribute `x.y` (usually, an assignment statement `x.y=value`, but also, e.g., `setattr(x, 'y', value)`), Python calls `x.__setattr__('y', value)`. Python always calls `__setattr__` for *any* attribute binding on *x*—a major difference from `__getattr__` (in this respect, `__setattr__` is closer to `__getattribute__`). To avoid recursion, when `x.__setattr__` binds *x*'s attributes, it must modify `x.__dict__` directly (e.g., via `x.__dict__[name]=value`); or better, `__setattr__` can delegate to the superclass (call `super().__setattr__('y', value)`). Python ignores the return value of `__setattr__`. If `__setattr__` is absent (i.e., inherited from object), and `C.y` is not an overriding descriptor, Python usually translates `x.y=z` into `x.__dict__['y']=z` (however, `__setattr__` also works fine with `__slots__`).
`__str__`	`__str__(self)` Like print(*x*), `str(x)` calls `x.__str__()` to get an informal, concise string representation of *x*. If `__str__` is absent, Python calls `x.__repr__`. `__str__` should return a convenient human-readable string, even when that entails some approximation.

Special Methods for Containers

An instance can be a *container* (a sequence, mapping, or set—mutually exclusive concepts[9]). For maximum usefulness, containers should provide special methods `__getitem__`, `__contains__`, and `__iter__` (and, if mutable, also `__setitem__` and `__delitem__`), plus nonspecial methods discussed in the following sections. In many cases, you can obtain suitable implementations of the nonspecial methods by extending the appropriate abstract base class from the `collections.abc` module, such as `Sequence`, `MutableSequence`, and so on, as covered in "Abstract Base Classes" on page 150.

Sequences

In each item-access special method, a sequence that has *L* items should accept any integer *key* such that `-L<=key<L`.[10] For compatibility with built-in sequences, a negative index *key*, `0>key>=-L`, should be equivalent to `key+L`. When *key* has an invalid type, indexing should raise a `TypeError` exception. When *key* is a value of a valid type but out of range, indexing should raise an `IndexError` exception. For sequence classes that do not define `__iter__`, the **`for`** statement relies on these requirements, as do built-in functions that take iterable arguments. Every item-access special method of a sequence should also, if at all practical, accept as its

9 Third-party extensions can also define types of containers that are not sequences, not mappings, and not sets.

10 Lower bound included, upper bound excluded—as always, the norm for Python.

index argument an instance of the built-in type `slice` whose `start`, `step`, and `stop` attributes are `int`s or `None`; the *slicing* syntax relies on this requirement, as covered in "Container slicing" on page 149.

A sequence should also allow concatenation (with another sequence of the same type) by `+`, and repetition by `*` (multiplication by an integer). A sequence should therefore have special methods `__add__`, `__mul__`, `__radd__`, and `__rmul__`, covered in "Special Methods for Numeric Objects" on page 155; in addition, *mutable* sequences should have equivalent in-place methods `__iadd__` and `__imul__`. A sequence should be meaningfully comparable to another sequence of the same type, implementing *lexicographic* comparison, like lists and tuples do. (Inheriting from the `Sequence` or `MutableSequence` abstract base class does not suffice to fulfill all of these requirements; inheriting from `MutableSequence`, at most, only supplies `__iadd__`.)

Every sequence should have the nonspecial methods covered in "List methods" on page 67: `count` and `index` in any case, and, if mutable, then also `append`, `insert`, `extend`, `pop`, `remove`, `reverse`, and `sort`, with the same signatures and semantics as the corresponding methods of lists. (Inheriting from the `Sequence` or `MutableSequence` abstract base class does suffice to fulfill these requirements, except for `sort`.)

An immutable sequence should be hashable if, and only if, all of its items are. A sequence type may constrain its items in some ways (for example, accepting only string items), but that is not mandatory.

Mappings

A mapping's item-access special methods should raise a `KeyError` exception, rather than `IndexError`, when they receive an invalid *`key`* argument value of a valid type. Any mapping should define the nonspecial methods covered in "Dictionary Methods" on page 71: `copy`, `get`, `items`, `keys`, and `values`. A mutable mapping should also define the methods `clear`, `pop`, `popitem`, `setdefault`, and `update`. (Inheriting from the `Mapping` or `MutableMapping` abstract base class fulfills these requirements, except for `copy`.)

An immutable mapping should be hashable if all of its items are. A mapping type may constrain its keys in some ways—for example, accepting only hashable keys, or (even more specifically) accepting, say, only string keys—but that is not mandatory. Any mapping should be meaningfully comparable to another mapping of the same type (at least for equality and inequality, although not necessarily for ordering comparisons).

Sets

Sets are a peculiar kind of container: they are neither sequences nor mappings and cannot be indexed, but they do have a length (number of elements) and are iterable. Sets also support many operators (`&`, `|`, `^`, and `-`, as well as membership tests and comparisons) and equivalent nonspecial methods (`intersection`, `union`, and so on). If you implement a set-like container, it should be polymorphic to Python built-in sets, covered in "Sets" on page 48. (Inheriting from the `Set` or `MutableSet` abstract base class fulfills these requirements.)

An immutable set-like type should be hashable if all of its elements are. A set-like type may constrain its elements in some ways—for example, accepting only hashable elements, or (more specifically) accepting, say, only integer elements—but that is not mandatory.

Container slicing

When you reference, bind, or unbind a slicing such as *x*[*i*:*j*] or *x*[*i*:*j*:*k*] on a container *x* (in practice, this is only used with sequences), Python calls *x*'s applicable item-access special method, passing as *key* an object of a built-in type called a *slice object*. A slice object has the attributes `start`, `stop`, and `step`. Each attribute is **None** if you omit the corresponding value in the slice syntax. For example, **del** *x*[:3] calls *x*.`__delitem__`(*y*), where *y* is a slice object such that *y*.`stop` is 3, *y*.`start` is **None**, and *y*.`step` is **None**. It is up to container object *x* to appropriately interpret slice object arguments passed to *x*'s special methods. The method `indices` of slice objects can help: call it with your container's length as its only argument, and it returns a tuple of three nonnegative indices suitable as `start`, `stop`, and `step` for a loop indexing each item in the slice. For example, a common idiom in a sequence class's `__getitem__` special method to fully support slicing is:

```
def __getitem__(self, index):
    # Recursively special-case slicing
    if isinstance(index, slice):
        return self.__class__(self[x]
                              for x in range(*index.indices(len(self))))
    # Check index, and deal with a negative and/or out-of-bounds index
    index = operator.index(index)
    if index < 0:
        index += len(self)
    if not (0 <= index < len(self)):
        raise IndexError
    # Index is now a correct int, within range(len(self))
    # ...rest of __getitem__, dealing with single-item access...
```

This idiom uses generator expression (genexp) syntax and assumes that your class's `__init__` method can be called with an iterable argument to create a suitable new instance of the class.

Container methods

The special methods `__getitem__`, `__setitem__`, `__delitem__`, `__iter__`, `__len__`, and `__contains__` expose container functionality (see Table 4-2).

Object-Oriented Python

Table 4-2. Container methods

`__contains__`	`__contains__(self, item)`
	The Boolean test *y* **in** *x* calls *x*.`__contains__(`*y*`)`. When *x* is a sequence, or set-like, `__contains__` should return **True** when *y* equals the value of an item in *x*. When *x* is a mapping, `__contains__` should return **True** when *y* equals the value of a key in *x*. Otherwise, `__contains__` should return **False**. When `__contains__` is absent and *x* is iterable, Python performs *y* **in** *x* as follows, taking time proportional to `len(`*x*`)`:
	`for z in x:`
	`    if y==z:`
	`        return True`
	`return False`

`__delitem__`	`__delitem__(self, key)` For a request to unbind an item or slice of *x* (typically **del** *x*[*key*]), Python calls *x*.`__delitem__(`*key*`)`. A container *x* should have `__delitem__` if *x* is mutable and items (and possibly slices) can be removed.
`__getitem__`	`__getitem__(self, key)` When you access *x*[*key*] (i.e., when you index or slice container *x*), Python calls *x*.`__getitem__(`*key*`)`. All (non-set-like) containers should have `__getitem__`.
`__iter__`	`__iter__(self)` For a request to loop on all items of *x* (typically **for** *item* **in** *x*), Python calls *x*.`__iter__()` to get an iterator on *x*. The built-in function `iter(`*x*`)` also calls *x*.`__iter__()`. When `__iter__` is absent, `iter(`*x*`)` synthesizes and returns an iterator object that wraps *x* and yields *x*`[0]`, *x*`[1]`, and so on, until one of these indexings raises an `IndexError` exception to indicate the end of the container. However, it is best to ensure that all of the container classes you code have `__iter__`.
`__len__`	`__len__(self)` Calling `len(`*x*`)` calls *x*.`__len__()` (and so do other built-in functions that need to know how many items are in container *x*). `__len__` should return an `int`, the number of items in *x*. Python also calls *x*.`_len__()` to evaluate *x* in a Boolean context, when `__bool__` is absent; in this case, a container is falsy if and only if the container is empty (i.e., the container's length is `0`). All containers should have `__len__`, unless it's just too expensive for the container to determine how many items it contains.
`__setitem__`	`__setitem__(self, key, value)` For a request to bind an item or slice of *x* (typically an assignment *x*[*key*]=*value*), Python calls *x*.`__setitem__(`*key*, *value*`)`. A container *x* should have `__setitem__` if *x* is mutable, so items, and maybe slices, can be added or rebound.

Abstract Base Classes

Abstract base classes (ABCs) are an important pattern in object-oriented design: they're classes that cannot be directly instantiated, but exist to be extended by concrete classes (the more usual kind of classes, ones that *can* be instantiated).

One recommended approach to OO design (attributed to Arthur J. Riel) is to never extend a concrete class.[11] If two concrete classes have enough in common to tempt you to have one of them inherit from the other, proceed instead by making an *abstract* base class that subsumes all they have in common, and have each concrete class extend that ABC. This approach avoids many of the subtle traps and pitfalls of inheritance.

Python offers rich support for ABCs—enough to make them a first-class part of Python's object model.[12]

The abc module

The standard library module `abc` supplies metaclass `ABCMeta` and class `ABC` (subclassing `abc.ABC` makes `abc.ABCMeta` the metaclass, and has no other effect).

When you use `abc.ABCMeta` as the metaclass for any class *`C`*, this makes *`C`* an ABC and supplies the class method *`C`*`.register`, callable with a single argument: that single argument can be any existing class (or built-in type) *`X`*.

Calling *`C`*`.register(`*`X`*`)` makes *`X`* a *virtual* subclass of *`C`*, meaning that `issubclass(`*`X`*`, `*`C`*`)` returns **`True`**, but *`C`* does not appear in *`X`*`.__mro__`, nor does *`X`* inherit any of *`C`*'s methods or other attributes.

Of course, it's also possible to have a new class *`Y`* inherit from *`C`* in the normal way, in which case *`C`* does appear in *`Y`*`.__mro__`, and *`Y`* inherits all of *`C`*'s methods, as usual in subclassing.

An ABC *`C`* can also optionally override class method `__subclasshook__`, which `issubclass(`*`X`*`, `*`C`*`)` calls with the single argument *`X`* (*`X`* being any class or type). When *`C`*`.__subclasshook__(`*`X`*`)` returns **`True`**, then so does `issubclass(`*`X`*`, `*`C`*`)`; when *`C`*`.__subclasshook__(`*`X`*`)` returns **`False`**, then so does `issubclass(`*`X`*`, `*`C`*`)`. When *`C`*`.__subclasshook__(`*`X`*`)` returns `NotImplemented`, then `issubclass(`*`X`*`, `*`C`*`)` proceeds in the usual way.

The `abc` module also supplies the decorator `abstractmethod` to designate methods that must be implemented in inheriting classes. You can define a property as abstract by using both the `property` and `abstractmethod` decorators, in that order.[13] Abstract methods and properties can have implementations (available to subclasses via the `super` built-in), but the point of making methods and properties abstract is that you can instantiate a nonvirtual subclass *`X`* of an ABC *`C`* only if *`X`* overrides every abstract property and method of *`C`*.

11 See, for example, "Avoid Extending Classes" by Bill Harlan.

12 For a related concept focused on type checking, see `typing.Protocols`, covered in "Protocols" on page 179.

13 The `abc` module does include the `abstractproperty` decorator, which combines these two, but `abstractproperty` is deprecated, and new code should use the two decorators as described.

ABCs in the collections module

`collections` supplies many ABCs, in `collections.abc`.[14] Some of these ABCs accept as a virtual subclass any class defining or inheriting a specific abstract method, as listed in Table 4-3.

Table 4-3. Single-method ABCs

ABC	Abstract methods
`Callable`	`__call__`
`Container`	`__contains__`
`Hashable`	`__hash__`
`Iterable`	`__iter__`
`Sized`	`__len__`

The other ABCs in `collections.abc` extend one or more of these, adding more abstract methods and/or *mixin* methods implemented in terms of the abstract methods. (When you extend any ABC in a concrete class, you *must* override the abstract methods; you can also override some or all of the mixin methods, when that helps improve performance, but you don't have to—you can just inherit them, when this results in performance that's sufficient for your purposes.)

Table 4-4 details the ABCs in `collections.abc` that directly extend the preceding ones.

Table 4-4. ABCs with additional methods

ABC	Extends	Abstract methods	Mixin methods
`Iterator`	`Iterable`	`__next__`	`__iter__`

`Mapping`	`Container`
	`Iterable`
	`Sized`
		`__getitem__`
		`__iter__`
		`__len__`
			`__contains__`
			`__eq__`
			`__ne__`
			`getitems`
			`keys`
			`values`

`MappingView`	`Sized`		`__len__`

14 For backward compatibility these ABCs were also accessible in the `collections` module until Python 3.9, but the compatibility imports were removed in Python 3.10. New code should import these ABCs from `collections.abc`.

ABC	Extends	Abstract methods	Mixin methods
Sequence	Container Iterable Sized	__getitem__ __len__	__contains__ __iter__ __reversed__ count index
Set	Container Iterable Sized	__contains__ __iter __len__	__and__ [a] __eq__ __ge__ [b] __gt__ __le__ __lt__ __ne__ __or__ __sub__ __xor__ isdisjoint

[a] For sets and mutable sets, many dunder methods are equivalent to nonspecial methods in the concrete class `set`; e.g., `__add__` is like `intersection` and `__iadd__` is like `intersection_update`.

[b] For sets, the ordering methods reflect the concept of *subset*: `s1 <= s2` means "`s1` is a subset of or equal to `s2`."

Table 4-5 details the ABCs in this module that further extend the previous ones.

Table 4-5. The remaining ABCs in `collections.abc`

ABC	Extends	Abstract methods	Mixin methods
ItemsView	MappingView Set		__contains__ __iter__
KeysView	MappingView Set		__contains__ __iter__
MutableMapping	Mapping	__delitem__ __getitem__ __iter__ __len_ __setitem__	Mapping's methods, plus: clear pop popitem setdefault update

ABC	Extends	Abstract methods	Mixin methods
MutableSequence	Sequence	__delitem__ __getitem__ __len__ __setitem__ insert	Sequence's methods, plus: __iadd__ append extend pop remove reverse
MutableSet	Set	__contains__ __iter __len__ add discard	Set's methods, plus: __iand__ __ior__ __isub__ __ixor__ clear pop remove
ValuesView	MappingView		__contains__ __iter__

See the online docs for further details and usage examples.

ABCs in the numbers module

numbers supplies a hierarchy (also known as a *tower*) of ABCs representing various kinds of numbers. Table 4-6 lists the ABCs in the numbers module.

Table 4-6. ABCs supplied by the numbers module

ABC	Description
Number	The root of the hierarchy. Includes numbers of *any* kind; need not support any given operation.
Complex	Extends Number. Must support (via special methods) conversions to complex and bool, +, -, *, /, ==, !=, and abs, and, directly, the method conjugate and properties real and imag.
Real	Extends Complex.[a] Additionally, must support (via special methods) conversion to float, math.trunc, round, math.floor, math.ceil, divmod, //, %, <, <=, >, and >=.
Rational	Extends Real. Additionally, must support the properties numerator and denominator.
Integral	Extends Rational.[b] Additionally, must support (via special methods) conversion to int, **, and bitwise operations <<, >>, &, ^, |, and ~.

[a] So, every int or float has a property real equal to its value, and a property imag equal to 0.

[b] So, every int has a property numerator equal to its value, and a property denominator equal to 1.

See the online docs for notes on implementing your own numeric types.

Special Methods for Numeric Objects

An instance may support numeric operations by means of many special methods. Some classes that are not numbers also support some of the special methods in Table 4-7 in order to overload operators such as + and *. In particular, sequences should have special methods __add__, __mul__, __radd__, and __rmul__, as mentioned in "Sequences" on page 43. When one of the binary methods (such as __add__, __sub__, etc.) is called with an operand of an unsupported type for that method, the method should return the built-in singleton NotImplemented.

Table 4-7. Special methods for numeric objects

__abs__, __invert__, __neg__, __pos__	__abs_(self), __invert__(self), __neg__(self), __pos__(self) The unary operators abs(*x*), ~*x*, -*x*, and +*x*, respectively, call these methods.
__add__, __mod__, __mul__, __sub__	__add__ (self, *other*), __mod__(self, *other*), __mul__(self, *other*), __sub__(self, *other*) The operators *x* + *y*, *x* % *y*, *x* * *y*, and *x* - *y*, respectively, call these methods, usually for arithmetic computations.
__and__, __lshift__, __or__, __rshift__, __xor__	__and__(self, *other*), __lshift__(self, *other*), __or__(self, *other*), __rshift_(self, *other*), __xor__(self, *other*) The operators *x* & *y*, *x* << *y*, *x* | *y*, *x* >> *y*, and *x* ^ *y*, respectively, call these methods, usually for bitwise operations.
__complex__, __float__, __int__	__complex__(self), __float__(self), __int__(self) The built-in types complex(*x*), float(*x*), and int(*x*), respectively, call these methods.
__divmod__	__divmod__(self, *other*) The built-in function divmod(*x*, *y*) calls *x*.__divmod__(*y*). __divmod__ should return a pair (*quotient*, *remainder*) equal to (*x* // *y*, *x* % *y*).
__floordiv__, __truediv__	__floordiv__(self, *other*), __truediv__(self, *other*) The operators *x* // *y* and *x* / *y*, respectively, call these methods, usually for arithmetic division.

Object-Oriented Python

`__iadd__`, `__ifloordiv__`, `__imod__`, `__imul__`, `__isub__`, `__itruediv__`, `__imatmul__`	`__iadd__(self, other)`, `__ifloordiv__(self, other)`, `__imod__(self, other)`, `__imul__(self, other)`, `__isub__(self, other)`, `__itruediv__(self, other)`, `__imatmul__(self, other)` The augmented assignments x += y, x //= y, x %= y, x *= y, x -= y, x /= y, and x @= y, respectively, call these methods. Each method should modify x in place and return `self`. Define these methods when x is mutable (i.e., when x *can* change in place).
`__iand__`, `__ilshift__`, `__ior__`, `__irshift__`, `__ixor__`	`__iand_(self, other)`, `__ilshift_(self, other)`, `__ior__(self, other)`, `__irshift__(self, other)`, `__ixor__(self, other)` The augmented assignments x &= y, x <<= y, x \= y, x >>= y, and x ^= y, respectively, call these methods. Each method should modify x in place and return `self`. Define these methods when x is mutable (i.e., when x *can* change in place).
`__index__`	`__index__(self)` Like `__int__`, but meant to be supplied only by types that are alternative implementations of integers (in other words, all of the type's instances can be exactly mapped into integers). For example, out of all the built-in types, only `int` supplies `__index__`; `float` and `str` don't, although they do supply `__int__`. Sequence indexing and slicing internally use `__index__` to get the needed integer indices.
`__ipow__`	`__ipow__(self,other)` The augmented assignment x **= y calls `x.__ipow__(y)`. `__ipow__` should modify x in place and return `self`.
`__matmul__`	`__matmul__(self, other)` The operator x @ y calls this method, usually for matrix multiplication.
`__pow__`	`__pow__(self,other[, modulo])` x ** y and `pow(x, y)` both call `x.__pow__(y)`, while `pow(x, y, z)` calls `x.__pow__(y, z)`. `x.__pow__(y, z)` should return a value equal to the expression `x.__pow__(y) % z`.
`__radd__`, `__rmod__`, `__rmul__`, `__rsub__`, `__rmatmul__`	`__radd__(self, other)`, `__rmod__(self, other)`, `__rmul__(self, other)`, `__rsub__(self, other)`, `__rmatmul__(self, other)` The operators y + x, y / x, y % x, y * x, y - x, and y @ x, respectively, call these methods on x when y doesn't have the needed method `__add__`, `__truediv__`, and so on, or when that method returns `NotImplemented`.

`__rand__`, `__rlshift__`, `__ror__`, `__rrshift__`, `__rxor__`	`__rand__(self, *other*)`, `__rlshift__(self, *other*)`, `__ror__(self, *other*)`, `__rrshift__(self, *other*)`, `__rxor__(self, *other*)` The operators *y* & *x*, *y* << *x*, *y* | *x*, *y* >> *x*, and *x* ^ *y*, respectively, call these methods on *x* when *y* doesn't have the needed method `__and__`, `__lshift__`, and so on, or when that method returns `NotImplemented`.
`__rdivmod__`	`__rdivmod_(self, *other*)` The built-in function `divmod(*y*, *x*)` calls `*x*.__rdivmod__(*y*)` when *y* doesn't have `__divmod__`, or when that method returns `NotImplemented`. `__rdivmod__` should return a pair `(*remainder*, *quotient*)`.
`__rpow__`	`__rpow__(self,*other*)` *y* ** *x* and `pow(*y*, *x*)` call `*x*.__rpow__(*y*)` when *y* doesn't have `__pow__`, or when that method returns `NotImplemented`. There is no three-argument form in this case.

Decorators

In Python, you often use *higher-order functions*: callables that accept a function as an argument and return a function as their result. For example, descriptor types such as `staticmethod` and `classmethod`, covered in "Class-Level Methods" on page 135, can be used, within class bodies, as follows:

```
def f(cls, ...):
    # ...definition of f snipped...
f = classmethod(f)
```

However, having the call to `classmethod` textually *after* the **`def`** statement hurts code readability: while reading *f*'s definition, the reader of the code is not yet aware that *f* is going to become a class method rather than an instance method. The code is more readable if the mention of `classmethod` comes *before* the `def`. For this purpose, use the syntax form known as *decoration*:

```
@classmethod
def f(cls, ...):
    # ...definition of f snipped...
```

The decorator, here `@classmethod`, must be immediately followed by a **`def`** statement and means that *f* = *classmethod*(*f*) executes right after the **`def`** statement (for whatever name *f* the **`def`** defines). More generally, `@*expression*` evaluates the expression (which must be a name, possibly qualified, or a call) and binds the result to an internal temporary name (say, *__aux*); any decorator must be immediately followed by a **`def`** (or **`class`**) statement, and means that *f* = *__aux*(*f*) executes right after the **`def`** or **`class`** statement (for whatever name *f* the **`def`** or **`class`** defines). The object bound to *__aux* is known as a *decorator*, and it's said to *decorate* function or class *f*.

Decorators are a handy shorthand for some higher-order functions. You can apply decorators to any **def** or **class** statement, not just in class bodies. You may code custom decorators, which are just higher-order functions accepting a function or class object as an argument and returning a function or class object as the result. For example, here is a simple example decorator that does not modify the function it decorates, but rather prints the function's docstring to standard output at function definition time:

```
def showdoc(f):
    if f.__doc__:
        print(f'{f.__name__}: {f.__doc__}')
    else:
        print(f'{f.__name__}: No docstring!')
    return f

@showdoc
def f1():
    """a docstring"""  # prints: f1: a docstring

@showdoc
def f2():
    pass               # prints: f2: No docstring!
```

The standard library module `functools` offers a handy decorator, `wraps`, to enhance decorators built by the common "wrapping" idiom:

```
import functools

def announce(f):
    @functools.wraps(f)
    def wrap(*a, **k):
        print(f'Calling {f.__name__}')
        return f(*a, **k)
    return wrap
```

Decorating a function *f* with `@announce` causes a line announcing the call to be printed before each call to *f*. Thanks to the `functools.wraps(`*f*`)` decorator, the wrapper adopts the name and docstring of the wrappee: this is useful, for example, when calling the built-in `help` on such a decorated function.

Metaclasses

Any object, even a class object, has a type. In Python, types and classes are also first-class objects. The type of a class object is also known as the class's *metaclass*.[15] An object's behavior is mostly determined by the type of the object. This also holds for classes: a class's behavior is mostly determined by the class's metaclass. Metaclasses

15 Strictly speaking, the type of a class *C* could be said to be the metaclass only of *instances* of *C* rather than of *C* itself, but this subtle semantic distinction is rarely, if ever, observed in practice.

are an advanced subject, and you may want to skip the rest of this section. However, fully grasping metaclasses can lead you to a deeper understanding of Python; very occasionally, it can be useful to define your own custom metaclasses.

Alternatives to Custom Metaclasses for Simple Class Customization

While a custom metaclass lets you tweak classes' behaviors in pretty much any way you want, it's often possible to achieve some customizations more simply than by coding a custom metaclass.

When a class *C* has or inherits a class method `__init_subclass__`, Python calls that method whenever you subclass *C*, passing the newly built subclass as the only positional argument. `__init_subclass__` can also have named parameters, in which case Python passes corresponding named arguments found in the class statement that performs the subclassing. As a purely illustrative example:

```
>>> class C:
...     def __init_subclass__(cls, foo=None, **kw):
...         print(cls, kw)
...         cls.say_foo = staticmethod(lambda: f'*{foo}*')
...         super().__init_subclass__(**kw)
...
>>> class D(C, foo='bar'):
...     pass
...
<class '__main__.D'> {}
>>> D.say_foo()
'*bar*'
```

The code in `__init_subclass__` can alter `cls` in any applicable, post-class-creation way; essentially, it works like a class decorator that Python automatically applies to any subclass of `C`.

Another special method used for customization is `__set_name__`, which lets you ensure that instances of descriptors added as class attributes know what class you're adding them to, and under which names. At the end of the **class** statement that adds *ca* to class *C* with name *n*, when the type of *ca* has the method `__set_name__`, Python calls *ca*`.__set_name__(`*C*, *n*`)`. For example:

```
>>> class Attrib:
...     def __set_name__(self, cls, name):
...         print(f'Attribute {name!r} added to {cls}')
...
>>> class AClass:
...     some_name = Attrib()
...
Attribute 'some_name' added to <class '__main__.AClass'>
>>>
```

Object-Oriented Python

How Python Determines a Class's Metaclass

The **`class`** statement accepts optional named arguments (after the bases, if any). The most important named argument is `metaclass`, which, if present, identifies the new class's metaclass. Other named arguments are allowed only if a non-`type` metaclass is present, in which case they are passed on to the optional `__prepare__` method of the metaclass (it's entirely up to the `__prepare__` method to make use of such named arguments).[16] When the named argument `metaclass` is absent, Python determines the metaclass by inheritance; for classes with no explicitly specified bases, the metaclass defaults to `type`.

Python calls the `__prepare__` method, if present, as soon as it determines the metaclass, as follows:

```
class M:
    def __prepare__(classname, *classbases, **kwargs):
        return {}
    # ...rest of M snipped...
class X(onebase, another, metaclass=M, foo='bar'):
    # ...body of X snipped...
```

Here, the call is equivalent to `M.__prepare__('X', onebase, another, foo='bar')`. `__prepare__`, if present, must return a mapping (usually just a dictionary), which Python uses as the *d* mapping in which it executes the class body. If `__prepare__` is absent, Python uses a new, initially empty `dict` as *d*.

How a Metaclass Creates a Class

Having determined the metaclass *M*, Python calls *M* with three arguments: the class name (a `str`), the tuple of base classes *t*, and the dictionary (or other mapping resulting from `__prepare__`) *d* in which the class body just finished executing.[17] The call returns the class object *C*, which Python then binds to the class name, completing the execution of the **`class`** statement. Note that this is in fact an instantiation of type *M*, so the call to *M* executes `M.__init__(C, namestring, t, d)`, where *C* is the return value of `M.__new__(M, namestring, t, d)`, just as in any other instantiation.

After Python creates the class object *C*, the relationship between class *C* and its type (`type(C)`, normally *M*) is the same as that between any object and its type. For example, when you call the class object *C* (to create an instance of *C*), `M.__call__` executes, with class object *C* as the first argument.

---

16 Or when a base class has `__init_subclass__`, in which case the named arguments are passed to that method, as covered in "Alternatives to Custom Metaclasses for Simple Class Customization" on page 159.

17 This is similar to calling `type` with three arguments, as described in "Dynamic class definition using the type built-in function" on page 133.

Note the benefit, in this context, of the approach described in "Per Instance Methods" on page 140, whereby special methods are looked up only on the class, not on the instance. Calling `C` to instantiate it must execute the metaclass's `M.__call__`, whether or not `C` has a per instance attribute (method) `__call__` (i.e., independently of whether *instances* of `C` are or aren't callable). This way, the Python object model avoids having to make the relationship between a class and its metaclass an ad hoc special case. Avoiding ad hoc special cases is a key to Python's power: Python has few, simple, general rules, and applies them consistently.

Defining and using your own metaclasses

It's easy to define custom metaclasses: inherit from `type` and override some of its methods. You can also perform most of the tasks for which you might consider creating a metaclass with `__new__`, `__init__`, `__getattribute__`, and so on, without involving metaclasses. However, a custom metaclass can be faster, since special processing is done only at class creation time, which is a rare operation. A custom metaclass lets you define a whole category of classes in a framework that magically acquire whatever interesting behavior you've coded, quite independently of what special methods the classes themselves may choose to define.

To alter a specific class in an explicit way, a good alternative is often to use a class decorator, as mentioned in "Decorators" on page 157. However, decorators are not inherited, so the decorator must be explicitly applied to each class of interest.[18] Metaclasses, on the other hand, *are* inherited; in fact, when you define a custom metaclass `M`, it's usual to also define an otherwise empty class `C` with metaclass `M`, so that other classes requiring `M` can just inherit from `C`.

Some behavior of class objects can be customized only in metaclasses. The following example shows how to use a metaclass to change the string format of class objects:

```
class MyMeta(type):
    def __str__(cls):
        return f'Beautiful class {cls.__name__!r}'
class MyClass(metaclass=MyMeta):
    pass
x = MyClass()
print(type(x))      # prints: Beautiful class 'MyClass'
```

A substantial custom metaclass example

Suppose that, programming in Python, we miss C's `struct` type: an object that is just a bunch of data attributes, in order, with fixed names (data classes, covered in the following section, fully address this requirement, which makes this example

18 `__init_subclass__`, covered in "Alternatives to Custom Metaclasses for Simple Class Customization" on page 159, works much like an "inherited decorator," so it's often an alternative to a custom metaclass.

a purely illustrative one). Python lets us easily define a generic `Bunch` class that is similar, apart from the fixed order and names:

```
class Bunch:
    def __init__(self, **fields):
        self.__dict__ = fields
p = Bunch(x=2.3, y=4.5)
print(p)       # prints: <_main__.Bunch object at 0x00AE8B10>
```

A custom metaclass can exploit the fact that attribute names are fixed at class creation time. The code shown in Example 4-1 defines a metaclass, `MetaBunch`, and a class, `Bunch`, to let us write code like:

```
class Point(Bunch):
    """A Point has x and y coordinates, defaulting to 0.0,
       and a color, defaulting to 'gray'-and nothing more,
       except what Python and the metaclass conspire to add,
       such as __init__ and __repr__.
    """
    x = 0.0
    y = 0.0
    color = 'gray'
# example uses of class Point
q = Point()
print(q)                    # prints: Point()
p = Point(x=1.2, y=3.4)
print(p)                    # prints: Point(x=1.2, y=3.4)
```

In this code, the `print` calls emit readable string representations of our `Point` instances. `Point` instances are quite memory lean, and their performance is basically the same as for instances of the simple class `Bunch` in the previous example (there is no extra overhead due to implicit calls to special methods). Example 4-1 is quite substantial, and following all its details requires a grasp of aspects of Python discussed later in this book, such as strings (covered in Chapter 9) and module warnings (covered in "The warnings Module" on page 538). The identifier `mcl` used in Example 4-1 stands for "metaclass," clearer in this special advanced case than the habitual case of `cls` standing for "class."

Example 4-1. The `MetaBunch` metaclass

```
import warnings
class MetaBunch(type):
    """
    Metaclass for new and improved "Bunch": implicitly defines
    __slots__, __init__, and __repr__ from variables bound in
    class scope.
    A class statement for an instance of MetaBunch (i.e., for a
    class whose metaclass is MetaBunch) must define only
    class-scope data attributes (and possibly special methods, but
    NOT __init__ and __repr__). MetaBunch removes the data
    attributes from class scope, snuggles them instead as items in
```

```python
    a class-scope dict named __dflts__, and puts in the class a
    __slots__ with those attributes' names, an __init__ that takes
    as optional named arguments each of them (using the values in
    __dflts__ as defaults for missing ones), and a __repr__ that
    shows the repr of each attribute that differs from its default
    value (the output of __repr__ can be passed to __eval__ to make
    an equal instance, as per usual convention in the matter, if
    each non-default-valued attribute respects that convention too).
    The order of data attributes remains the same as in the class body.
    """
    def __new__(mcl, classname, bases, classdict):
        """Everything needs to be done in __new__, since
           type.__new__ is where __slots__ are taken into account.
        """
        # Define as local functions the __init__ and __repr__ that
        # we'll use in the new class
        def __init__(self, **kw):
            """__init__ is simple: first, set attributes without
               explicit values to their defaults; then, set those
               explicitly passed in kw.
            """
            for k in self.__dflts__:
                if not k in kw:
                    setattr(self, k, self.__dflts__[k])
            for k in kw:
                setattr(self, k, kw[k])
        def __repr__(self):
            """__repr__ is minimal: shows only attributes that
               differ from default values, for compactness.
            """
            rep = [f'{k}={getattr(self, k)!r}'
                    for k in self.__dflts__
                    if getattr(self, k) != self.__dflts__[k]
                  ]
            return f'{classname}({', '.join(rep)})'
        # Build the newdict that we'll use as class dict for the
        # new class
        newdict = {'__slots__': [], '__dflts__': {},
                   '__init__': __init__, '__repr__' :__repr__,}
        for k in classdict:
            if k.startswith('__') and k.endswith('__'):
                # Dunder methods: copy to newdict, or warn
                # about conflicts
                if k in newdict:
                    warnings.warn(f'Cannot set attr {k!r}'
                                  f' in bunch-class {classname!r}')
                else:
                    newdict[k] = classdict[k]
            else:
                # Class variables: store name in __slots__, and
                # name and value as an item in __dflts__
                newdict['__slots__'].append(k)
```

Object-Oriented Python

```
                newdict['__dflts__'][k] = classdict[k]
        # Finally, delegate the rest of the work to type.__new__
        return super().__new__(mcl, classname, bases, newdict)

class Bunch(metaclass=MetaBunch):
    """For convenience: inheriting from Bunch can be used to get
       the new metaclass (same as defining metaclass= yourself).
    """
    pass
```

Data Classes

As the previous `Bunch` class exemplified, a class whose instances are just a bunch of named data items is a great convenience. Python's standard library covers that with the `dataclasses` module.

The main feature of the `dataclasses` module you'll be using is the `dataclass` function: a decorator you apply to any class whose instances you want to be just such a bunch of named data items. As a typical example, consider the following code:

```
import dataclasses
@dataclasses.dataclass
class Point:
    x: float
    y: float
```

Now you can call, say, `pt = Point(0.5, 0.5)` and get a variable with attributes `pt.x` and `pt.y`, each equal to `0.5`. By default, the `dataclass` decorator has imbued the class `Point` with an `__init__` method accepting initial floating-point values for attributes `x` and `y`, and a `__repr__` method ready to appropriately display any instance of the class:

```
>>> pt

Point(x=0.5, y=0.5)
```

The `dataclass` function takes many optional named parameters to let you tweak details of the class it decorates. The parameters you may be explicitly using most often are listed in Table 4-8.

Table 4-8. Commonly used `dataclass` function parameters

Parameter name	Default value and resulting behavior
`eq`	**`True`** When **`True`**, generates an `__eq__` method (unless the class defines one)
`frozen`	**`False`** When **`True`**, makes each instance of the class read-only (not allowing rebinding or deletion of attributes)

Parameter name	Default value and resulting behavior
init	**True** When **True**, generates an __init__ method (unless the class defines one)
kw_only	**False** **3.10+** When **True**, forces arguments to __init__ to be named, not positional
order	**False** When **True**, generates order-comparison special methods (__le__, __lt__, and so on) unless the class defines them
repr	**True** When **True**, generates a __repr__ method (unless the class defines one)
slots	**False** **3.10+** When **True**, adds the appropriate __slots__ attribute to the class (saving some amount of memory for each instance, but disallowing the addition of other, arbitrary attributes to class instances)

The decorator also adds to the class a __hash__ method (allowing instances to be keys in a dictionary and members of a set) when that is safe (typically, when you set frozen to **True**). You may force the addition of __hash__ even when that's not necessarily safe, but we earnestly recommend that you don't; if you insist, check the online docs for details on how to do so.

If you need to tweak each instance of a dataclass after the automatically generated __init__ method has done the core work of assigning each instance attribute, define a method called __post_init__, and the decorator will ensure it is called right after __init__ is done.

Say you wish to add an attribute to Point to capture the time when the point was created. This could be added as an attribute assigned in __post_init__. Add the attribute create_time to the members defined for Point, as type float with a default value of 0, and then add an implementation for __post_init__:

```
def __post_init__(self):
    self.create_time = time.time()
```

Now if you create the variable pt = Point(0.5, 0.5), printing it out will display the creation timestamp, similar to the following:

```
>>> pt

Point(x=0.5, y=0.5, create_time=1645122864.3553088)
```

Like regular classes, dataclasses can also support additional methods and properties, such as this method that computes the distance between two Points and this property that returns the distance from a Point at the origin:

```
def distance_from(self, other):
    dx, dy = self.x - other.x, self.y - other.y
    return math.hypot(dx, dy)
```

```
    @property
    def distance_from_origin(self):
        return self.distance_from(Point(0, 0))
```

For example:

```
>>> pt.distance_from(Point(-1, -1))
2.1213203435596424
>>> pt.distance_from_origin
0.7071067811865476
```

The `dataclasses` module also supplies `asdict` and `astuple` functions, each taking a `dataclass` instance as the first argument and returning, respectively, a `dict` and a `tuple` with the class's fields. Furthermore, the module supplies a `field` function that you may use to customize the treatment of some of a `dataclass`'s fields (i.e., instance attributes), and several other specialized functions and classes needed only for very advanced, esoteric purposes; to learn all about them, check out the online docs.

Enumerated Types (Enums)

When programming, you'll often want to create a set of related values that catalog or *enumerate* the possible values for a particular property or program setting,[19] whatever they might be: terminal colors, logging levels, process states, playing card suits, clothing sizes, or just about anything else you can think of. An *enumerated type* (*enum*) is a type that defines a group of such values, with symbolic names that you can use as typed global constants. Python provides the `Enum` class and related subclasses in the `enum` module for defining enums.

Defining an enum gives your code a set of symbolic constants that represent the values in the enumeration. In the absence of enums, constants might be defined as `int`s, as in this code:

```
# colors
RED = 1
GREEN = 2
BLUE = 3

# sizes
XS = 1
S = 2
M = 3
L = 4
XL = 5
```

19 Don't confuse this concept with the unrelated `enumerate` built-in function, covered in Chapter 8, which generates (*number*, *item*) pairs from an iterable.

However, in this design, there is no mechanism to warn against nonsense expressions like `RED > XL` or `L * BLUE`, since they are all just `int`s. There is also no logical grouping of the colors or sizes.

Instead, you can use an `Enum` subclass to define these values:

```
from enum import Enum, auto

class Color(Enum):
    RED = 1
    GREEN = 2
    BLUE = 3

class Size(Enum):
    XS = auto()
    S = auto()
    M = auto()
    L = auto()
    XL = auto()
```

Now, code like `Color.RED > Size.S` stands out visually as incorrect, and at runtime raises a Python `TypeError`. Using `auto()` automatically assigns incrementing `int` values beginning with `1` (in most cases, the actual values assigned to enum members are not meaningful).

Calling Enum Creates a Class, Not an Instance

Surprisingly, when you call `enum.Enum()`, it doesn't return a newly built *instance*, but rather a newly built *subclass*. So, the preceding snippet is equivalent to:

```
from enum import Enum
Color = Enum('Color', ('RED', 'GREEN', 'BLUE'))
Size = Enum('Size', 'XS S M L XL')
```

When you *call* `Enum` (rather than explicitly subclassing it in a class statement), the first argument is the name of the subclass you're building; the second argument gives all the names of that subclass's members, either as a sequence of strings or as a single whitespace-separated (or comma-separated) string.

We recommend that you define `Enum` subclasses using class inheritance syntax, instead of this abbreviated form. The **`class`** form is more visually explicit, so it is easier to see if a member is missing, misspelled, or added later.

The values within an enum are called its *members*. It is conventional to use all uppercase characters to name enum members, treating them much as though they were manifest constants. Typical uses of the members of an enum are assignment and identity checking:

```python
    while process_state is ProcessState.RUNNING:
        # running process code goes here
        if processing_completed():
            process_state = ProcessState.IDLE
```

You can obtain all members of an `Enum` by iterating over the `Enum` class itself, or from the class's `__members__` attribute. `Enum` members are all global singletons, so comparison with **`is`** and **`is not`** is preferred over `==` or `!=`.

The `enum` module contains several classes[20] to support different forms of enums, listed in Table 4-9.

Table 4-9. `enum` classes

Class	Description
`Enum`	Basic enumeration class; member values can be any Python object, typically `int`s or `str`s, but do not support `int` or `str` methods. Useful for defining enumerated types whose members are an unordered group.
`Flag`	Used to define enums that you can combine with operators `|`, `&`, `^`, and `~`; member values must be defined as `int`s to support these bitwise operations (Python, however, assumes no ordering among them). `Flag` members with a `0` value are falsy; other members are truthy. Useful when you create or check values with bitwise operations (e.g., file permissions). To support bitwise operations, you generally use powers of 2 (1, 2, 4, 8, etc.) as member values.
`IntEnum`	Equivalent to **`class`** `IntEnum(`*`int`*`, `*`Enum`*`)`; member values are `int`s and support all `int` operations, including ordering. Useful when order among values is significant, such as when defining logging levels.
`IntFlag`	Equivalent to **`class`** `IntFlag(`*`int`*`, `*`Flag`*`)`; member values are `int`s (usually, powers of 2) supporting all `int` operations, including comparisons.
`StrEnum`	**3.11+** Equivalent to **`class`** `StrEnum(`*`str`*`, `*`Enum`*`)`; member values are `str`s and support all `str` operations.

The `enum` module also defines some support functions, listed in Table 4-10.

Table 4-10. `enum` support functions

Support function	Description
`auto`	Autoincrements member values as you define them. Values typically start at `1` and increment by 1; for `Flag`, increments are in powers of 2.
`unique`	Class decorator to ensure that members' values differ from each other.

20 `enum`'s specialized metaclass behaves so differently from the usual `type` metaclass that it's worth pointing out all the differences between `enum.Enum` and ordinary classes. You can read about this in the "How are Enums different?" section of Python's online documentation.

The following example shows how to define a `Flag` subclass to work with the file permissions in the `st_mode` attribute returned from calling `os.stat` or `Path.stat` (for a description of the `stat` functions, see Chapter 11):

```
import enum
import stat

class Permission(enum.Flag):
    EXEC_OTH = stat.S_IXOTH
    WRITE_OTH = stat.S_IWOTH
    READ_OTH = stat.S_IROTH
    EXEC_GRP = stat.S_IXGRP
    WRITE_GRP = stat.S_IWGRP
    READ_GRP = stat.S_IRGRP
    EXEC_USR = stat.S_IXUSR
    WRITE_USR = stat.S_IWUSR
    READ_USR = stat.S_IRUSR

    @classmethod
    def from_stat(cls, stat_result):
        return cls(stat_result.st_mode & 0o777)

from pathlib import Path

cur_dir = Path.cwd()
dir_perm = Permission.from_stat(cur_dir.stat())
if dir_perm & Permission.READ_OTH:
    print(f'{cur_dir} is readable by users outside the owner group')

# the following raises TypeError: Flag enums do not support order
# comparisons
print(Permission.READ_USR > Permission.READ_OTH)
```

Using enums in place of arbitrary `ints` or `strs` can add readability and type integrity to your code. You can find more details on the classes and methods of the `enum` module in the Python docs.

5
Type Annotations

Annotating your Python code with type information is an optional step which can be very helpful during development and maintenance of a large project or a library. Static type checkers and lint tools help identify and locate data type mismatches in function arguments and return values. IDEs can use these *type annotations* (also called *type hints*) to improve autocompletion and to provide pop-up documentation. Third-party packages and frameworks can use type annotations to tailor runtime behavior, or to autogenerate code based on type annotations for methods and variables.

Type annotations and checking in Python continue to evolve, and touch on many complicated issues. This chapter covers some of the most common use cases for type annotations; you can find more comprehensive material in the resources listed at the end of the chapter.

> **Type Annotation Support Varies by Python Version**
> Python's features supporting type annotations have evolved from version to version, with some significant additions and deletions. The rest of this chapter will describe the type annotation support in the most recent versions of Python (3.10 and later), with notes to indicate features that might be present or absent in other versions.

History

Python is, fundamentally, a *dynamically typed* language. This lets you rapidly develop code by naming and using variables without having to declare them. Dynamic typing allows for flexible coding idioms, generic containers, and polymorphic data handling without requiring explicit definition of interface types or class hierarchies. The downside is that the language offers no help during development in flagging variables of incompatible types being passed to or returned from functions. In place of the development-time compile step that some languages utilize to detect and report data type issues, Python relies on developers to maintain comprehensive unit tests, especially (though far from exclusively![1]) to uncover data type errors by re-creating the runtime environment in a series of test cases.

Type Annotations Are Not Enforced

Type annotations are *not* enforced at runtime. Python does not perform any type validation or data conversion based on them; the executable Python code is still responsible for using variables and function arguments properly. However, type annotations must be syntactically correct. A late-imported or dynamically imported module containing an invalid type annotation raises a `SyntaxError` exception in your running Python program, just like any invalid Python statement.

Historically, the absence of any kind of type checking was often seen as a shortcoming of Python, with some programmers citing this as a reason for choosing other programming languages. However, the community wanted Python to maintain its runtime type freedom, so the logical approach was to add support for static type checks performed at development time by lint-like tools (described further in the following section) and IDEs. Some attempts were made at type checking based on parsing function signatures or docstrings. Guido van Rossum cited several cases on the Python Developers mailing list showing that type annotations could be helpful; for example, when maintaining large legacy codebases. With an annotation syntax, development tools could perform static type checks to highlight variable and function usages that conflict with the intended types.

The first official version of type annotations used specially formatted comments to indicate variable types and return codes, as defined in PEP 484, a provisional PEP for Python 3.5.[2] Using comments allowed for rapid implementation of, and experimentation with, the new typing syntax, without having to modify the Python compiler itself.[3] The third-party package `mypy` gained broad acceptance performing static type checking using these comments. With the adoption of PEP 526 in Python 3.6, type annotations were fully incorporated into the Python language itself, with a supporting `typing` module added to the standard library.

1 Strong, extensive unit tests will also guard against many business logic problems that no amount of type checking would ever catch for you—so, type hints are not to be used *instead of* unit tests, but *in addition* to them.

2 The *syntax* for type annotation was introduced in Python 3.0, but only later were its *semantics* specified.

3 This approach was also compatible with Python 2.7 code, still in widespread use at the time.

Type-Checking Utilities

As type annotations have become an established part of Python, type-checking utilities and IDE plug-ins have also become part of the Python ecosystem.

mypy

The standalone `mypy` utility continues to be a mainstay for static type checking, always up-to-date (give or take a Python version!) with evolving Python type annotation forms. `mypy` is also available as a plug-in for editors including Vim, Emacs, and SublimeText, and for the Atom, PyCharm, and VS Code IDEs. (PyCharm, VS Code, and Wing IDE also incorporate their own type-checking features separate from `mypy`.) The most common command for running `mypy` is simply **`mypy my_python_script.py`**.

You can find more detailed usage examples and command-line options in the `mypy` online documentation, as well as a cheat sheet that serves as a handy reference. Code examples later in this section will include example `mypy` error messages to illustrate the kinds of Python errors that can be caught using type checking.

Other Type Checkers

Other type checkers to consider using include:

MonkeyType
: Instagram's MonkeyType uses the `sys.setprofile` hook to detect types dynamically at runtime; like `pytype` (see below), it can also generate a *.pyi* (stub) file instead of, or in addition to, inserting type annotations in the Python code file itself.

`pydantic`
: `pydantic` also works at runtime, but it does not generate stubs or insert type annotations; rather, its primary goal is to parse inputs and ensure that Python code receives clean data. As described in the online docs, it also allows you to extend its validation features for your own environment. See "FastAPI" on page 605 for a simple example.

Pylance
: Pylance is a type checking module primarily meant to embed Pyright (see below) into VS Code.

Pyre
: Facebook's Pyre can also generate *.pyi* files. It currently does not run on Windows, unless you have the Windows Subsystem for Linux (WSL) installed.

Pyright
: Pyright is Microsoft's static type checking tool, available as a command-line utility and a VS Code extension.

`pytype`
: `pytype` from Google is a static type checker that focuses on *type inferencing* (and offers advice even in the absence of type hints) in addition to type annotations. Type inferencing offers a powerful capability for detecting type errors even in code without annotations. `pytype` can also generate *.pyi* files and merge stub files back into *.py* sources (the most recent versions of `mypy` are following suit on this). Currently, `pytype` does not run on Windows unless you first install WSL.

The emergence of type-checking applications from multiple major software organizations is a testimonial to the widespread interest in the Python developer community in using type annotations.

Type Annotation Syntax

A *type annotation* is specified in Python using the form:

```
identifier: type_specification
```

`type_specification` can be any Python expression, but usually involves one or more built-in types (for example, just mentioning a Python type is a perfectly valid expression) and/or attributes imported from the `typing` module (discussed in the following section). The typical form is:

```
type_specifier[type_parameter, ...]
```

Here are some examples of type expressions used as type annotations for a variable:

```
import typing

# an int
count: int

# a list of ints, with a default value
counts: list[int] = []

# a dict with str keys, values are tuples containing 2 ints and a str
employee_data: dict[str, tuple[int, int, str]]

# a callable taking a single str or bytes argument and returning a bool
str_predicate_function: typing.Callable[[str | bytes], bool]

# a dict with str keys, whose values are functions that take and return
# an int
str_function_map: dict[str, typing.Callable[[int], int]] = {
    'square': lambda x: x * x,
    'cube': lambda x: x * x * x,
}
```

Note that **lambda**s do *not* accept type annotations.

Typing Syntax Changes in Python 3.9 and 3.10

One of the most significant changes in type annotations during the span of Python versions covered in this book was the support added in Python 3.9 for using built-in Python types, as shown in these examples.

-3.9 Prior to Python 3.9, these annotations required the use of type names imported from the typing module, such as Dict, List, Tuple, etc.

3.10+ Python 3.10 added support for using | to indicate alternative types, as a more readable, concise alternative to the Union[*atype*, *btype*, ...] notation. The | operator can also be used to replace Optional[*atype*] with *atype* | None.

For instance, the previous str_predicate_function definition would take one of the following forms, depending on your version of Python:

```
# prior to 3.10, specifying alternative types
# requires use of the Union type
from typing import Callable, Union
str_predicate_function: Callable[Union[str, bytes], bool]

# prior to 3.9, built-ins such as list, tuple, dict,
# set, etc. required types imported from the typing
# module
from typing import Dict, Tuple, Callable, Union
employee_data: Dict[str, Tuple[int, int, str]]
str_predicate_function: Callable[Union[str, bytes], bool]
```

Type Annotations

To annotate a function with a return type, use the form:

```
def identifier(argument, ...) -> type_specification :
```

where each *argument* takes the form:

```
identifier[: type_specification[ = default_value]]
```

Here's an example of an annotated function:

```
def pad(a: list[str], min_len: int = 1, padstr: str = ' ') -> list[str]:
    """Given a list of strings and a minimum length, return a copy of
       the list extended with "padding" strings to be at least the
       minimum length.
    """
    return a + ([padstr] * (min_len - len(a)))
```

Note that when an annotated parameter has a default value, PEP 8 recommends using spaces around the equals sign.

Forward-Referencing Types That Are Not Yet Fully Defined

At times, a function or variable definition needs to reference a type that has not yet been defined. This is quite common in class methods, or methods that must define arguments or return values of the type of the current class. Those function signatures are parsed at compile time, and at that point the type is not yet defined. For example, this `classmethod` fails to compile:

```
class A:
    @classmethod
    def factory_method(cls) -> A:
        # ... method body goes here ...
```

Since class `A` has not yet been defined when Python compiles `factory_method`, the code raises `NameError`.

The problem can be resolved by enclosing the return type `A` in quotes:

```
class A:
    @classmethod
    def factory_method(cls) -> 'A':
        # ... method body goes here ...
```

A future version of Python may defer the evaluation of type annotations until runtime, making the enclosing quotes unnecessary (Python's Steering Committee is evaluating various possibilities). You can preview this behavior using `from __future__ import annotations`.

The typing Module

The `typing` module supports type hints. It contains definitions that are useful when creating type annotations, including:

- Classes and functions for defining types
- Classes and functions for modifying type expressions
- Abstract base classes (ABCs)
- Protocols
- Utilities and decorators
- Classes for defining custom types

Types

The initial implementations of the `typing` module included definitions of types corresponding to Python built-in containers and other types, as well as types from standard library modules. Many of these types have since been deprecated (see below), but some are still useful, since they do not correspond directly to any

Python built-in type. Table 5-1 lists the typing types still useful in Python 3.9 and later.

Table 5-1. Useful definitions in the typing module

Type	Description
Any	Matches any type.
AnyStr	Equivalent to str | bytes. AnyStr is meant to be used to annotate function arguments and return types where either string type is acceptable, but the types should not be mixed between multiple arguments, or arguments and return types.
BinaryIO	Matches streams with binary (bytes) content such as those returned from open with mode='b', or io.BytesIO.
Callable	Callable[[*argument_type*, ...], *return_type*] Defines the type signature for a callable object. Takes a list of types corresponding to the arguments to the callable, and a type for the return value of the function. If the callable takes no arguments, indicate this with an empty list, []. If the callable has no return value, use **None** for *return_type*.
IO	Equivalent to BinaryIO | TextIO.
Literal [*expression*,...]	**3.8+** Specifies a list of valid values that the variable may take.
LiteralString	**3.11+** Specifies a str that must be implemented as a literal quoted value. Used to guard against leaving code open to injection attacks.
NoReturn	Use as the return type for functions that "run forever," such as those that call http.serve_forever or event_loop.run_forever without returning. This is *not* intended for functions that simply return with no explicit value; for those use -> **None**. More discussion of return types can be found in "Adding Type Annotations to Existing Code (Gradual Typing)" on page 193.
Self	**3.11+** Use as the return type for instance functions that **return** self (and in a few other cases, as exemplified in PEP 673).
TextIO	Matches streams with text (str) content, such as those returned from open with mode='t', or io.StringIO.

-3.9 Prior to 3.9, the definitions in the typing module were used to create types representing built-in types, such as List[int] for a list of ints. From 3.9 onward, these names are deprecated, as their corresponding built-in or standard library types now support the [] syntax: a list of ints is now simply typed using list[int]. Table 5-2 lists the definitions from the typing module that were necessary prior to Python 3.9 for type annotations using built-in types.

Table 5-2. Python built-in types and their pre-3.9 definitions in the `typing` module

Built-in type	Pre-3.9 typing module equivalent
`dict`	`Dict`
`frozenset`	`FrozenSet`
`list`	`List`
`set`	`Set`
`str`	`Text`
`tuple`	`Tuple`
`type`	`Type`
`collections.ChainMap`	`ChainMap`
`collections.Counter`	`Counter`
`collections.defaultdict`	`DefaultDict`
`collections.deque`	`Deque`
`collections.OrderedDict`	`OrderedDict`
`re.Match`	`Match`
`re.Pattern`	`Pattern`

Type Expression Parameters

Some types defined in the `typing` module modify other type expressions. The types listed in Table 5-3 provide additional typing information or constraints for the modified types in *`type_expression`*.

Table 5-3. Type expression parameters

Parameter	Usage and description
`Annotated`	`Annotated[`*`type_expression, expression, ...`*`]` **3.9+** Extends the *`type_expression`* with additional metadata. The extra metadata values for function *`fn`* can be retrieved at runtime using `get_type_hints(`*`fn`*`, include_extras=`**`True`**`)`.
`ClassVar`	`ClassVar[`*`type_expression`*`]` Indicates that the variable is a class variable, and should not be assigned as an instance variable.
`Final`	`Final[`*`type_expression`*`]` **3.8+** Indicates that the variable should not be written to or overridden in a subclass.

Parameter	Usage and description
Optional	Optional[*type_expression*] Equivalent to *type_expression* | **None**. Often used for named arguments with a default value of **None**. (Optional does not automatically define **None** as the default value, so you must still follow it with =**None** in a function signature.) **3.10+** With the availability of the | operator for specifying alternative type attributes, there is a growing consensus to prefer *type_expression* | **None** over using Optional[*type_expression*].

Abstract Base Classes

Just as for built-in types, the initial implementations of the typing module included definitions of types corresponding to abstract base classes in the collections.abc module. Many of these types have since been deprecated (see below), but two definitions have been retained as aliases to ABCs in collections.abc (see Table 5-4).

Table 5-4. Abstract base class aliases

Type	Method subclasses must implement
Hashable	__hash__
Sized	__len__

-3.9 Prior to Python 3.9, the following definitions in the typing module represented abstract base classes defined in the collections.abc module, such as Sequence[int] for a sequence of ints. From 3.9 onward, these names in the typing module are deprecated, as their corresponding types in collections.abc now support the [] syntax:

AbstractSet	Container	Mapping
AsyncContextManager	ContextManager	MappingView
AsyncGenerator	Coroutine	MutableMapping
AsyncIterable	Generator	MutableSequence
AsyncIterator	ItemsView	MutableSet
Awaitable	Iterable	Reversible
ByteString	Iterator	Sequence
Collection	KeysView	ValuesView

Protocols

The typing module defines several *protocols*, which are similar to what some other languages call "interfaces." Protocols are abstract base classes intended to concisely express constraints on a type, ensuring it contains certain methods. Each protocol currently defined in the typing module relates to a single special method, and its name starts with Supports followed by the name of the method (however, other libraries, such as those defined in typeshed, need not follow the same constraints). Protocols can be used as minimal abstract classes to determine a class's support for that protocol's capabilities: all that a class needs to do to comply with a protocol is to implement the protocol's special method(s).

Table 5-5 lists the protocols defined in the typing module.

Table 5-5. Protocols in the typing module and their required methods

Protocol	Has method
SupportsAbs	`__abs__`
SupportsBytes	`__bytes__`
SupportsComplex	`__complex__`
SupportsFloat	`__float__`
SupportsIndex **3.8+**	`__index__`
SupportsInt	`__int__`
SupportsRound	`__round__`

A class does not have to explicitly inherit from a protocol in order to satisfy `issubclass(cls, protocol_type)`, or for its instances to satisfy `isinstance(obj, protocol_type)`. The class simply has to implement the method(s) defined in the protocol. Imagine, for example, a class implementing Roman numerals:

```
class RomanNumeral:
    """Class representing some Roman numerals and their int
       values.
    """
    int_values = {'I': 1, 'II': 2, 'III': 3, 'IV': 4, 'V': 5}

    def __init__(self, label: str):
        self.label = label

    def __int__(self) -> int:
        return RomanNumeral.int_values[self.label]
```

To create an instance of this class (to, say, represent a sequel in a movie title) and get its value, you could use the following code:

```
>>> movie_sequel = RomanNumeral('II')
>>> print(int(movie_sequel))
2
```

RomanNumeral satisfies issubclass, and isinstance checks with SupportsInt because it implements __int__, even though it does not inherit explicitly from the protocol class SupportsInt:[4]

```
>>> issubclass(RomanNumeral, typing.SupportsInt)
True
>>> isinstance(movie_sequel, typing.SupportsInt)
True
```

Utilities and Decorators

Table 5-6 lists commonly used functions and decorators defined in the typing module; it's followed by a few examples.

Table 5-6. Commonly used functions and decorators defined in the typing module

Function/decorator	Usage and description
cast	cast(*type*, *var*) Signals to the static type checker that *var* should be considered as type *type*. Returns *var*; at runtime there is no change, conversion, or validation of *var*. See the example after the table.
final	@final **3.8+** Used to decorate a method in a class definition, to warn if the method is overridden in a subclass. Can also be used as a class decorator, to warn if the class itself is being subclassed.
get_args	get_args(*custom_type*) Returns the arguments used to construct a custom type.
get_origin	get_origin(*custom_type*) **3.8+** Returns the base type used to construct a custom type.
get_type_hints	get_type_hints(*obj*) Returns results as if accessing *obj*.__annotations__. Can be called with optional globalns and localns namespace arguments to resolve forward type references given as strings, and/or with optional Boolean include_extras argument to include any nontyping annotations added using Annotations.
NewType	NewType(*type_name*, *type*) Defines a custom type derived from *type*. *type_name* is a string that should match the local variable to which the NewType is being assigned. Useful for distinguishing different uses for common types, such as a str used for an employee name versus a str used for a department name. See "NewType" on page 190 for more on this function.

4 And SupportsInt uses the runtime_checkable decorator.

Function/decorator	Usage and description
no_type_check	@no_type_check Used to indicate that annotations are not intended to be used as type information. Can be applied to a class or function.
no_type_check_ decorator	@no_type_check_decorator Used to add no_type_check behavior to another decorator.
overload	@overload Used to allow defining multiple methods with the same name but differing types in their signatures. See the example after the table.
runtime_ checkable	@runtime_checkable **3.8+** Used to add isinstance and issubclass support for custom protocol classes. See "Using Type Annotations at Runtime" on page 191 for more on this decorator.
TypeAlias	*name*: TypeAlias = *type_expression* **3.10+** Used to distinguish the definition of a type alias from a simple assignment. Most useful in cases where *type_expression* is a simple class name or a string value referring to a class that is not yet defined, which might look like an assignment. TypeAlias may only be used at module scope. A common use is to make it easier to consistently reuse a lengthy type expression, e.g.: Number: TypeAlias = int | float | Fraction. See "TypeAlias" on page 189 for more on this annotation.
type_check_only	@type_check_only Used to indicate that the class or function is only used at type-checking time and is not available at runtime.
TYPE_CHECKING	A special constant that static type checkers evaluate as **True** but that is set to **False** at runtime. Use this to skip imports of large, slow-to-import modules used solely to support type checking (so that the import is not needed at runtime).
TypeVar	TypeVar(*type_name*, **types*) Defines a type expression element for use in complex generic types using Generic. *type_name* is a string that should match the local variable to which the TypeVar is being assigned. If *types* are not given, then the associated Generic will accept any type. If *types* are given, then the Generic will only accept instances of any of the provided types or their subclasses. Also accepts the named Boolean arguments covariant and contravariant (both defaulting to False), and the argument bound. These are described in more detail in "Generics and TypeVars" on page 184 and in the typing module docs.

Use overload at type-checking time to flag named arguments that must be used in particular combinations. In this case, fn must be called with either a str key and int value pair, or with a single bool value:

```
@typing.overload
def fn(*, key: str, value: int):
    ...
```

```
@typing.overload
def fn(*, strict: bool):
    ...

def fn(**kwargs):
    # implementation goes here, including handling of differing
    # named arguments
    pass

# valid calls
fn(key='abc', value=100)
fn(strict=True)

# invalid calls
fn(1)
fn('abc')
fn('abc', 100)
fn(key='abc')
fn(True)
fn(strict=True, value=100)
```

Note that the `overload` decorator is used purely for static type checking. To actually dispatch to different methods based on a parameter type at runtime, use `functools.singledispatch`.

Use the `cast` function to force a type checker to treat a variable as being of a particular type, within the scope of the cast:

```
def func(x: list[int] | list[str]):
    try:
        return sum(x)
    except TypeError:
        x = cast(list[str], x)
        return ','.join(x)
```

Use cast with Caution

`cast` is a way of overriding any inferences or prior annotations that may be present at a particular place in your code. It may hide actual type errors in your code, rendering the type-checking pass incomplete or inaccurate. The `func` in the preceding example raises no `mypy` warnings itself, but fails at runtime if passed a list of mixed `int`s and `str`s.

Defining Custom Types

Just as Python's **`class`** syntax permits the creation of new runtime types and behavior, the `typing` module constructs discussed in this section enable the creation of specialized type expressions for advanced type checking.

The `typing` module includes three classes from which your classes can inherit to get type definitions and other default features, listed in Table 5-7.

Table 5-7. Base classes for defining custom types

`Generic`	`Generic[`*`type_var`*`, ...]` Defines a type-checking abstract base class for a class whose methods reference one or more `TypeVar`-defined types. Generics are described in more detail in the following subsection.
`NamedTuple`	`NamedTuple` A typed implementation of `collections.namedtuple`. See "NamedTuple" on page 186 for further details and examples.
`TypedDict`	`TypedDict` **3.8+** Defines a type-checking `dict` that has specific keys and value types for each key. See "TypedDict" on page 187 for details.

Generics and TypeVars

Generics are types that define a template for classes that can adapt the type annotations of their method signatures based on one or more type parameters. For instance, `dict` is a generic that takes two type parameters: the type for the dictionary keys and the type for the dictionary values. Here is how `dict` might be used to define a dictionary that maps color names to RGB triples:

```
color_lookup: dict[str, tuple[int, int, int]] = {}
```

The variable `color_lookup` will support statements like:

```
color_lookup['red'] = (255, 0, 0)
color_lookup['red'][2]
```

However, the following statements generate `mypy` errors, due to a mismatched key or value type:

```
color_lookup[0]
```

```
error: Invalid index type "int" for "dict[str, tuple[int, int, int]]";
expected type "str"
```

```
color_lookup['red'] = (255, 0, 0, 0)
```

```
error: Incompatible types in assignment (expression has type
"tuple[int, int, int, int]", target has type "tuple[int, int, int]")
```

Generic typing permits the definition of behavior in a class that is independent of the specific types of the objects that class works with. Generics are often used for defining container types, such as `dict`, `list`, `set`, etc. By defining a generic type, we avoid the necessity of exhaustively defining types for `DictOfStrInt`, `DictOfIntEmployee`, and so on. Instead, a generic `dict` is defined as `dict[`*`KT`*`, `*`VT`*`]`, where *`KT`* and *`VT`* are placeholders for the `dict`'s key type and value type, and the specific types for any particular `dict` can be defined when the `dict` is instantiated.

As an example, let's define a hypothetical generic class: an accumulator that can be updated with values, but which also supports an `undo` method. Since the accumulator is a generic container, we declare a `TypeVar` to represent the type of the contained objects:

```
import typing
T = typing.TypeVar('T')
```

The `Accumulator` class is defined as a subclass of `Generic`, with `T` as a type parameter. Here is the class declaration and its `__init__` method, which creates a contained list, initially empty, of objects of type `T`:

```
class Accumulator(typing.Generic[T]):
    def __init__(self):
        self._contents: list[T] = []
```

To add the `update` and `undo` methods, we define arguments that reference the contained objects as being of type `T`:

```
    def update(self, *args: T) -> None:
        self._contents.extend(args)

    def undo(self) -> None:
        # remove last value added
        if self._contents:
            self._contents.pop()
```

Lastly, we add `__len__` and `__iter__` methods so that `Accumulator` instances can be iterated over:

```
    def __len__(self) -> int:
        return len(self._contents)

    def __iter__(self) -> typing.Iterator[T]:
        return iter(self._contents)
```

Now this class can be used to write code using `Accumulator[int]` to collect a number of `int` values:

```
acc: Accumulator[int] = Accumulator()
acc.update(1, 2, 3)
print(sum(acc))  # prints 6
acc.undo()
print(sum(acc))  # prints 3
```

Because `acc` is an `Accumulator` containing `int`s, the following statements generate `mypy` error messages:

```
acc.update('A')
```

```
error: Argument 1 to "update" of "Accumulator" has incompatible type
"str"; expected "int"
```

```
print(''.join(acc))
```

```
error: Argument 1 to "join" of "str" has incompatible type
"Accumulator[int]"; expected "Iterable[str]"
```

Type Annotations

Restricting TypeVar to specific types

Nowhere in our `Accumulator` class do we ever invoke methods directly on the contained `T` objects themselves. For this example, the `T` `TypeVar` is purely untyped, so type checkers like `mypy` cannot infer the presence of any attributes or methods of the `T` objects. If the generic needs to access attributes of the `T` objects it contains, then `T` should be defined using a modified form of `TypeVar`.

Here are some examples of `TypeVar` definitions:

```
# T must be one of the types listed (int, float, complex, or str)
T = typing.TypeVar('T', int, float, complex, str)
# T must be the class MyClass or a subclass of the class MyClass
T = typing.TypeVar('T', bound=MyClass)
# T must implement __len__ to be a valid subclass of the Sized protocol
T = typing.TypeVar('T', bound=collections.abc.Sized)
```

These forms of `T` allow a generic defined on `T` to use methods from these types in `T`'s `TypeVar` definition.

NamedTuple

The `collections.namedtuple` function simplifies the definition of class-like tuple types that support named access to the tuple elements. `NamedTuple` provides a typed version of this feature, using a class with attributes-style syntax similar to `dataclasses` (covered in "Data Classes" on page 164). Here's a `NamedTuple` with four elements, with names, types, and optional default values:

```
class HouseListingTuple(typing.NamedTuple):
    address: str
    list_price: int
    square_footage: int = 0
    condition: str = 'Good'
```

`NamedTuple` classes generate a default constructor, accepting positional or named arguments for each named field:

```
listing1 = HouseListingTuple(
    address='123 Main',
    list_price=100_000,
    square_footage=2400,
    condition='Good',
)

print(listing1.address)  # prints: 123 Main
print(type(listing1))    # prints: <class 'HouseListingTuple'>
```

Attempting to create a tuple with too few elements raises a runtime error:

```
listing2 = HouseListingTuple(
    '123 Main',
)
```

```
# raises a runtime error: TypeError: HouseListingTuple.__new__()
# missing 1 required positional argument: 'list_price'
```

TypedDict

3.8+ Python `dict` variables are often difficult to decipher in legacy codebases, because `dict`s are used in two ways: as collections of key/value pairs (such as a mapping from user ID to username), and records mapping known field names to values. It is usually easy to see that a function argument is to be passed as a `dict`, but the actual keys and value types are dependent on the code that may call that function. Beyond simply defining that a `dict` may be a mapping of `str` values to `int` values, as in `dict[str, int]`, a `TypedDict` defines the expected keys and the types of each corresponding value. The following example defines a `TypedDict` version of the previous house listing type (note that `TypedDict` definitions do not accept default value definitions):

```
class HouseListingDict(typing.TypedDict):
    address: str
    list_price: int
    square_footage: int
    condition: str
```

`TypedDict` classes generate a default constructor, accepting named arguments for each defined key:

```
listing1 = HouseListingDict(
    address='123 Main',
    list_price=100_000,
    square_footage=2400,
    condition='Good',
)

print(listing1['address'])  # prints 123 Main
print(type(listing1))  # prints <class 'dict'>

listing2 = HouseListingDict(
    address='124 Main',
    list_price=110_000,
)
```

Unlike the `NamedTuple` example, `listing2` will not raise a runtime error, simply creating a `dict` with just the given keys. However, `mypy` will flag `listing2` as a type error with the message:

```
error: Missing keys ("square_footage", "condition") for TypedDict
"HouseListing"
```

To indicate to the type checker that some keys may be omitted (but to still validate those that are given), add `total=False` to the class declaration:

```
class HouseListing(typing.TypedDict, total=False):
    # ...
```

3.11+ Individual fields can also use the `Required` or `NotRequired` type annotations to explicitly mark them as required or optional:

```
class HouseListing(typing.TypedDict):
    address: typing.Required[str]
    list_price: int
    square_footage: typing.NotRequired[int]
    condition: str
```

`TypedDict` can be used to define a generic type, too:

```
T = typing.TypeVar('T')

class Node(typing.TypedDict, typing.Generic[T]):
    label: T
    neighbors: list[T]

n = Node(label='Acme', neighbors=['anvil', 'magnet', 'bird seed'])
```

Do Not Use the Legacy TypedDict(name, **fields) Format

To support backporting to older versions of Python, the initial release of `TypedDict` also let you use a syntax similar to that for `namedtuple`, such as:

```
HouseListing = TypedDict('HouseListing',
                         address=str,
                         list_price=int,
                         square_footage=int,
                         condition=str)
```

or:

```
HouseListing = TypedDict('HouseListing',
                         {'address': str,
                          'list_price': int,
                          'square_footage': int,
                          'condition': str})
```

These forms are deprecated in Python 3.11, and are planned to be removed in Python 3.13.

Note that `TypedDict` does not actually define a new type. Classes created by inheriting from `TypedDict` actually serve as `dict` factories, such that instances created from them *are* `dict`s. Reusing the previous code snippet defining the `Node` class, we can see this using the `type` built-in function:

```
n = Node(label='Acme', neighbors=['anvil', 'magnet', 'bird seed'])
print(type(n))            # prints: <class 'dict'>
print(type(n) is dict)    # prints: True
```

There is no special runtime conversion or initialization when using `TypedDict`; the benefits of `TypedDict` are those of static type checking and self documentation, which naturally accrue from using type annotations.

Which Should You Use, NamedTuple or TypedDict?

The two data types appear similar in terms of their supported features, but there are significant differences that should help you determine which one to use.

`NamedTuple`s are immutable, so they can be used as dictionary keys or stored in sets, and are inherently safe to share across threads. As a `NamedTuple` object is a tuple, you can get its property values in order simply by iterating over it. However, to get the attribute names, you need to use the special `__annotations__` attribute.

Since classes created with `TypedDict` are actually `dict` factories, instances created from them are `dict`s, with all the behavior and attributes of `dict`s. They are mutable, so their values can be updated without creating a new container instance, and they support all the `dict` methods, such as `keys`, `values`, and `items`. They are also easily serialized using JSON or `pickle`. However, being mutable, they cannot be used as keys in another `dict`, nor can they be stored in a `set`.

`TypedDict`s are more lenient than `NamedTuple`s about missing keys. When a key is omitted when constructing a `TypedDict`, there is no error (though you will get a type-check warning from the static type checker). On the other hand, if an attribute is omitted when constructing a `NamedTuple`, this will raise a runtime `TypeError`.

In short, there is no across-the-board rule for when to use a `NamedTuple` versus a `TypedDict`. Consider these alternative behaviors and how they relate to your program and its use of these data objects when deciding between a `NamedTuple` and a `TypedDict`—and don't forget the other, often preferable, alternative of using a `dataclass` (covered in "Data Classes" on page 164) instead!

Type Annotations

TypeAlias

3.10+ Defining a simple type alias can be misinterpreted as assigning a class to a variable. For instance, here we define a type for record identifiers in a database:

```
Identifier = int
```

To clarify that this statement is intended to define a custom type name for the purposes of type checking, use `TypeAlias`:

```
Identifier: TypeAlias = int
```

`TypeAlias` is also useful when defining an alias for a type that is not yet defined, and so referenced as a string value:

```
# Python will treat this like a standard str assignment
TBDType = 'ClassNotDefinedYet'

# indicates that this is actually a forward reference to a class
TBDType: TypeAlias = 'ClassNotDefinedYet'
```

`TypeAlias` types may only be defined at module scope. Custom types defined using `TypeAlias` are interchangeable with the target type. Contrast `TypeAlias` (which does not create a new type, just gives a new name for an existing one) with `NewType`, covered in the following section, which does create a new type.

NewType

`NewType` allows you to define application-specific subtypes, to avoid confusion that might result from using the same type for different variables. If your program uses `str` values for different types of data, for example, it is easy to accidentally interchange values. Suppose you have a program that models employees in departments. The following type declaration is not sufficiently descriptive—which is the key and which is the value?

```
employee_department_map: dict[str, str] = {}
```

Defining types for employee and department IDs makes this declaration clearer:

```
EmpId = typing.NewType('EmpId', str)
DeptId = typing.NewType('DeptId', str)
employee_department_map: dict[EmpId, DeptId] = {}
```

These type definitions will also allow type checkers to flag this incorrect usage:

```
def transfer_employee(empid: EmpId, to_dept: DeptId):
    # update department for employee
     employee_department_map[to_dept] = empid
```

Running `mypy` reports these errors for the line `employee_department_map[to_dept] = empid`:

```
error: Invalid index type "DeptId" for "Dict[EmpId, DeptId]"; expected
type "EmpId"
error: Incompatible types in assignment (expression has type "EmpId",
target has type "DeptId")
```

Using `NewType` often requires you to use `typing.cast` too; for example, to create an `EmpId`, you need to cast a `str` to the `EmpId` type.

You can also use `NewType` to indicate the desired implementation type for an application-specific type. For instance, the basic US postal zip code is five numeric digits. It is common to see this implemented using `int`, which becomes problematic with zip codes that have a leading `0`. To indicate that zip codes should be implemented using `str`, your code can define this type-checking type:

```
ZipCode = typing.NewType("ZipCode", str)
```

Annotating variables and function arguments using `ZipCode` will help flag incorrect uses of `int` for zip code values.

Using Type Annotations at Runtime

Function and class variable annotations can be introspected by accessing the function or class's `__annotations__` attribute (although a better practice is to instead call `inspect.get_annotations()`):

```
>>> def f(a:list[str], b) -> int:
...     pass
...
>>> f.__annotations__
{'a': list[str], 'return': <class 'int'>}
>>> class Customer:
...     name: str
...     reward_points: int = 0
...
>>> Customer.__annotations__
{'name': <class 'str'>, 'reward_points': <class 'int'>}
```

This feature is used by third-party packages such as `pydantic` and FastAPI to provide extra code generation and validation capabilities.

3.8+ To define your own custom protocol class that supports runtime checking with `issubclass` and `isinstance`, define that class as a subclass of `typing.Protocol`, with empty method definitions for the required protocol methods, and decorate the class with `@runtime_checkable` (covered in Table 5-6). If you *don't* decorate it with `@runtime_checkable`, you're still defining a `Protocol` that's quite usable for static type checking, but it won't be runtime-checkable with `issubclass` and `isinstance`.

For example, we could define a protocol that indicates that a class implements the `update` and `undo` methods as follows (the Python `Ellipsis`, `...`, is a convenient syntax for indicating an empty method definition):

```
T = typing.TypeVar('T')

@typing.runtime_checkable
class SupportsUpdateUndo(typing.Protocol):
    def update(self, *args: T) -> None:
        ...
    def undo(self) -> None:
        ...
```

Without making any changes to the inheritance path of `Accumulator` (defined in "Generics and TypeVars" on page 184), it now satisfies runtime type checks with `SupportsUpdateUndo`:

```
>>> issubclass(Accumulator, SupportsUpdateUndo)
True
```

```
>>> isinstance(acc, SupportsUpdateUndo)
True
```

In addition, any other class that implements `update` and `undo` methods will now qualify as a `SupportsUpdateUndo` "subclass."

How to Add Type Annotations to Your Code

Having seen some of the features and capabilities provided by using type annotations, you may be wondering about the best way to get started. This section describes a few scenarios and approaches to adding type annotations.

Adding Type Annotations to New Code

When you start writing a short Python script, adding type annotations may seem like an unnecessary extra burden. As a spinoff of the Two Pizza Rule, we suggest the Two Function Rule: as soon as your script contains two functions or methods, go back and add type annotations to the method signatures, and any shared variables or types as necessary. Use `TypedDict` to annotate any `dict` structures that are used in place of classes, so that `dict` keys get clearly defined up front or get documented as you go; use `NamedTuples` (or `dataclasses`: some of this book's authors *strongly* prefer the latter option) to define the specific attributes needed for those data "bundles."

If you are beginning a major project with many modules and classes, then you should definitely use type annotations from the beginning. They can easily make you more productive, as they help avoid common naming and typing mistakes and ensure you get more fully supported autocompletion while working in your IDE. This is even more important on projects with multiple developers: having documented types helps tell everyone on the team the expectations for types and values to be used across the project. Capturing these types in the code itself makes them immediately accessible and visible during development, much more so than separate documentation or specifications.

If you are developing a library to be shared across projects, then you should also use type annotations from the very start, most likely paralleling the function signatures in your API design. Having type annotations in a library will make life easier for your client developers, as all modern IDEs include type annotation plug-ins to support static type checking and function autocompletion and documentation. They will also help you when writing your unit tests, since you will benefit from the same rich IDE support.

For any of these projects, add a type-checking utility to your pre-commit hooks, so that you stay ahead of any type infractions that might creep into your new codebase. This way you can fix them as they occur, instead of waiting until you do a large commit and finding that you have made some fundamental typing errors in multiple places.

Adding Type Annotations to Existing Code (Gradual Typing)

Several companies that have run projects to apply type annotations to large existing codebases recommend an incremental approach, referred to as *gradual typing*. With gradual typing, you can work through your codebase in a stepwise manner, adding and validating type annotations a few classes or modules at a time.

Some utilities, like `mypy`, will let you add type annotations function by function. `mypy`, by default, skips functions without typed signatures, so you can methodically go through your codebase a few functions at a time. This incremental process allows you to focus your efforts on individual parts of the code, as opposed to adding type annotations everywhere and then trying to sort out an avalanche of type-checker errors.

Some recommended approaches are:

- Identify your most heavily used modules, and begin adding types to them, a method at a time. (These could be core application class modules, or widely shared utility modules.)
- Annotate a few methods at a time, so that type-checking issues get raised and resolved gradually.
- Use `pytype` or `pyre` inference to generate initial *.pyi* stub files (discussed in the following section). Then, steadily migrate types from the *.pyi* files, either manually or using automation such as `pytype`'s `merge_pyi` utility.
- Begin using type checkers in a lenient default mode, so that most code is skipped and you can focus attention on specific files. As work progresses, shift to a stricter mode so that remaining items are made more prominent, and files that have been annotated do not regress by taking on new nonannotated code.

Type Annotations

Using .pyi Stub Files

Sometimes you don't have access to Python type annotations. For example, you might be using a library that does not have type annotations, or using a module whose functions are implemented in C.

In these cases, you can use separate *.pyi* stub files containing just the related type annotations. Several of the type checkers mentioned at the beginning of this chapter can generate these stub files. You can download stub files for popular Python libraries, as well as the Python standard library itself, from the `typeshed` repository. You can maintain stub files from the Python source, or, using merging utilities available in some of the type checkers, integrate them back into the original Python source.

Do Type Annotations Get in the Way of Coding?

Type annotations carry some stigma, especially for those who have worked with Python for many years and are used to taking full advantage of Python's adaptive nature. Flexible method signatures like that of the built-in function `max`, which can take a single argument containing a sequence of values or multiple arguments containing the values to be maximized, have been cited as being especially challenging to type-annotate. Is this the fault of the code? Of typing? Of Python itself? Each of these explanations is possible.

In general, typing fosters a degree of formalism and discipline that can be more confining than the historical Python philosophy of "coding by and for consenting adults." Moving forward, we may find that the flexibility of style in older Python code is not wholly conducive to long-term use, reuse, and maintenance by those who are not the original code authors. As a recent PyCon presenter suggested, "Ugly type annotations hint at ugly code." (However, it may sometimes be the case, like for `max`, that it's the typing system that's not expressive enough.)

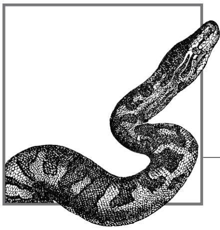
You can take the level of typing difficulty as an indicator of your method design. If your methods require multiple `Union` definitions, or multiple overrides for the same method using different argument types, perhaps your design is too flexible across multiple calling styles. You may be overdoing the flexibility of your API because Python allows it, but that might not always be a good idea in the long run. After all, as the Zen of Python says, "There should be one—and preferably only one—obvious way to do it." Maybe that should include "only one obvious way" to call your API!

Summary

Python has steadily risen to prominence as a powerful language and programming ecosystem, supporting important enterprise applications. What was once a utility language for scripting and task automation has become a platform for significant and complex applications affecting millions of users, used in mission-critical and even extraterrestrial systems.[5] Adding type annotations is a significant step in developing and maintaining these systems.

The online documentation for type annotations provides up-to-date descriptions, examples, and best practices as the syntax and practices for annotating types continue to evolve. The authors also recommend *Fluent Python*, 2nd edition, by Luciano Ramalho (O'Reilly), especially Chapters 8 and 15, which deal specifically with Python type annotations.

5 NASA's Jet Propulsion Lab used Python for the Persistence Mars Rover and the Ingenuity Mars Helicopter; the team responsible for the discovery of gravitational waves used Python both to coordinate the instrumentation and to analyze the resulting hoard of data.



6
Exceptions

Python uses *exceptions* to indicate errors and anomalies. When Python detects an error, it *raises* an exception—that is, Python signals the occurrence of an anomalous condition by passing an exception object to the exception propagation mechanism. Your code can explicitly raise an exception by executing a **`raise`** statement.

Handling an exception means catching the exception object from the propagation mechanism and taking actions as needed to deal with the anomalous situation. If a program does not handle an exception, the program terminates with an error message and traceback message. However, a program can handle exceptions and keep running, despite errors or other anomalies, by using the **`try`** statement with **`except`** clauses.

Python also uses exceptions to indicate some situations that are not errors, and not even abnormal. For example, as covered in "Iterators" on page 86, calling the `next` built-in function on an iterator raises `StopIteration` when the iterator has no more items. This is not an error; it is not even an anomaly, since most iterators run out of items eventually. The optimal strategies for checking and handling errors and other special situations in Python are therefore different from those in other languages; we cover them in "Error-Checking Strategies" on page 214.

This chapter shows how to use exceptions for errors and special situations. It also covers the `logging` module of the standard library, in "Logging Errors" on page 217, and the **`assert`** statement, in "The assert Statement" on page 219.

The try Statement

The **`try`** statement is Python's core exception handling mechanism. It's a compound statement with three kinds of optional clauses:

1. It may have zero or more **except** clauses, defining how to handle particular classes of exceptions.
2. If it has **except** clauses, then it may also have, right afterwards, one **else** clause, executed only if the **try** suite raised no exceptions.
3. Whether or not it has **except** clauses, it may have a single **finally** clause, unconditionally executed, with the behavior covered in "try/except/finally" on page 199.

Python's syntax requires the presence of at least one **except** clause or a **finally** clause, both of which might also be present in the same statement; **else** is only valid following one or more **except**s.

try/except

Here's the syntax for the **try/except** form of the **try** statement:

```
try:
    statement(s)
except [expression [as target]]:
    statement(s)
[else:
    statement(s)]
[finally:
    statement(s)]
```

This form of the **try** statement has one or more **except** clauses, as well as an optional **else** clause (and an optional **finally** clause, whose meaning does not depend on whether **except** and **else** clauses are present: we cover this in the following section).

The body of each **except** clause is known as an *exception handler*. The code executes when the *expression* in the **except** clause matches an exception object propagating from the **try** clause. *expression* is a class or tuple of classes, in parentheses, and matches any instance of one of those classes or their subclasses. The optional *target* is an identifier that names a variable that Python binds to the exception object just before the exception handler executes. A handler can also obtain the current exception object by calling the `exc_info` function (**3.11+** or the `exception` function) of the module `sys` (covered in Table 9-3).

Here is an example of the `try/except` form of the `try` statement:

```
try:
    1/0
    print('not executed')
except ZeroDivisionError:
    print('caught divide-by-0 attempt')
```

When an exception is raised, execution of the **try** suite immediately ceases. If a **try** statement has several **except** clauses, the exception propagation mechanism checks the **except** clauses in order; the first **except** clause whose expression matches the exception object executes as the handler, and the exception propagation mechanism checks no further **except** clauses after that.

Specific Before General

Place handlers for specific cases before handlers for more general cases: when you place a general case first, the more specific **except** clauses that follow never execute.

The last **except** clause need not specify an expression. An **except** clause without any expression handles any exception that reaches it during propagation. Such unconditional handling is rare, but it does occur, often in "wrapper" functions that must perform some extra task before re-raising an exception (see "The raise Statement" on page 200).

Avoid a "Bare Except" That Doesn't Re-Raise

Beware of using a "bare" **except** (an **except** clause without an expression) unless you're re-raising the exception in it: such sloppy style can make bugs very hard to find, since the bare **except** is overly broad and can easily mask coding errors and other kinds of bugs by allowing execution to continue after an unanticipated exception.

New programmers who are "just trying to get things to work" may even write code like:

```
try:
    # ...code that has a problem...
except:
    pass
```

This is a dangerous practice, since it catches important process-exiting exceptions such as `KeyboardInterrupt` or `SystemExit`—a loop with such an exception handler can't be exited with Ctrl-C, and possibly not even terminated with a system **kill** command. At the very least, such code should use **except** `Exception:`, which is still overly broad but at least does not catch the process-exiting exceptions.

Exception propagation terminates when it finds a handler whose expression matches the exception object. When a **try** statement is nested (lexically in the source code, or dynamically within function calls) in the **try** clause of another **try** statement, a handler established by the inner **try** is reached first on propagation, so it handles the exception when it matches it. This may not be what you want. Consider this example:

```
try:
    try:
        1/0
```

```
    except:
        print('caught an exception')
except ZeroDivisionError:
    print('caught divide-by-0 attempt')
# prints: caught an exception
```

In this case, it does not matter that the handler established by the clause **except** `ZeroDivisionError:` in the outer **try** clause is more specific than the catch-all **except**: in the inner **try** clause. The outer **try** does not enter into the picture: the exception doesn't propagate out of the inner **try**. For more on exception propagation, see "Exception Propagation" on page 204.

The optional **else** clause of **try/except** executes only when the **try** clause terminates normally. In other words, the **else** clause does not execute when an exception propagates from the **try** clause, or when the **try** clause exits with a **break**, **continue**, or **return** statement. Handlers established by **try/except** cover only the **try** clause, not the **else** clause. The **else** clause is useful to avoid accidentally handling unexpected exceptions. For example:

```
print(repr(value), 'is ', end=' ')
try:
    value + 0
except TypeError:
    # not a number, maybe a string...?
    try:
        value + ''
    except TypeError:
        print('neither a number nor a string')
    else:
        print('some kind of string')
else:
    print('some kind of number')
```

try/finally

Here's the syntax for the **try/finally** form of the **try** statement:

```
try:
    statement(s)
finally:
    statement(s)
```

This form has one **finally** clause, and no `else` clause (unless it also has one or more **except** clauses, as covered in the following section).

The **finally** clause establishes what is known as a *cleanup handler*. This code always executes after the **try** clause terminates in any way. When an exception propagates from the **try** clause, the **try** clause terminates, the cleanup handler executes, and the exception keeps propagating. When no exception occurs, the cleanup handler executes anyway, regardless of whether the **try** clause reaches its end or exits by executing a **break**, **continue**, or **return** statement.

Cleanup handlers established with **try/finally** offer a robust and explicit way to specify finalization code that must always execute, no matter what, to ensure consistency of program state and/or external entities (e.g., files, databases, network connections). Such assured finalization is nowadays usually best expressed via a *context manager* used in a **with** statement (see "The with Statement and Context Managers" on page 201). Here is an example of the **try/finally** form of the **try** statement:

```
f = open(some_file, 'w')
try:
    do_something_with_file(f)
finally:
    f.close()
```

and here is the corresponding, more concise and readable, example of using **with** for exactly the same purpose:

```
with open(some_file, 'w') as f:
    do_something_with_file(f)
```

Avoid break and return Statements in a finally Clause

A **finally** clause may contain one or more of the statements **continue**, **3.8+** **break**, or **return**. However, such usage may make your program less clear: exception propagation stops when such a statement executes, and most programmers would not expect propagation to be stopped within a **finally** clause. This usage may confuse people who are reading your code, so we recommend you avoid it.

try/except/finally

A **try/except/finally** statement, such as:

```
try:
    ...guarded clause...
except ...expression...:
    ...exception handler code...
finally:
    ...cleanup code...
```

is equivalent to the nested statement:

```
try:
    try:
        ...guarded clause...
    except ...expression...:
        ...exception handler code...
finally:
    ...cleanup code...
```

A **try** statement can have multiple **except** clauses, and optionally an **else** clause, before a terminating **finally** clause. In all variations, the effect is always as just shown—that is, it's just like nesting a **try/except** statement, with all the **except** clauses and the **else** clause, if any, into a containing **try/finally** statement.

The raise Statement

You can use the **raise** statement to raise an exception explicitly. **raise** is a simple statement with the following syntax:

```
raise [expression [from exception]]
```

Only an exception handler (or a function that a handler calls, directly or indirectly) can use **raise** without any expression. A plain **raise** statement re-raises the same exception object that the handler received. The handler terminates, and the exception propagation mechanism keeps going up the call stack, searching for other applicable handlers. Using **raise** without any expression is useful when a handler discovers that it is unable to handle an exception it receives, or can handle the exception only partially, so the exception should keep propagating to allow handlers up the call stack to perform their own handling and cleanup.

When *expression* is present, it must be an instance of a class inheriting from the built-in class `BaseException`, and Python raises that instance.

When **from** *exception* is included (which can only occur in an **except** block that receives *exception*), Python raises the received expression "nested" in the newly raised exception expression. "Exceptions "wrapping" other exceptions or tracebacks" on page 209 describes this in more detail.

Here's an example of a typical use of the **raise** statement:

```
def cross_product(seq1, seq2):
    if not seq1 or not seq2:
        raise ValueError('Sequence arguments must be non-empty') ❶
    return [(x1, x2) for x1 in seq1 for x2 in seq2]
```

❶ Some people consider raising a standard exception here to be inappropriate, and would prefer to raise an instance of a custom exception, as covered later in this chapter; this book's authors disagree with this opinion.

This `cross_product` example function returns a list of all pairs with one item from each of its sequence arguments, but first, it tests both arguments. If either argument is empty, the function raises `ValueError` rather than just returning an empty list as the list comprehension would normally do.

Check Only What You Need To

There is no need for `cross_product` to check whether `seq1` and `seq2` are iterable: if either isn't, the list comprehension itself raises the appropriate exception, presumably a `TypeError`.

Once an exception is raised, by Python itself or with an explicit **raise** statement in your code, it is up to the caller to either handle it (with a suitable **try/except** statement) or let it propagate further up the call stack.

> **Don't Use raise for Redundant Error Checks**
>
> Use the `raise` statement only to raise additional exceptions for cases that would normally be OK but that your specification defines to be errors. Do not use `raise` to duplicate the same error checking that Python already (implicitly) does on your behalf.

The with Statement and Context Managers

The **with** statement is a compound statement with the following syntax:

```
with expression [as varname] [, ...]:
    statement(s)

# 3.10+ multiple context managers for a with statement
# can be enclosed in parentheses
with (expression [as varname], ...):
    statement(s)
```

The semantics of **with** are equivalent to:

```
_normal_exit = True
_manager = expression
varname = _manager.__enter__()
try:
    statement(s)
except:
    _normal_exit = False
    if not _manager.__exit_(*sys.exc_info()):
        raise
    # note that exception does not propagate if __exit__ returns
    # a true value
finally:
    if _normal_exit:
        _manager.__exit__(None, None, None)
```

where `_manager` and `_normal_exit` are arbitrary internal names that are not used elsewhere in the current scope. If you omit the optional **as** *`varname`* part of the **with** clause, Python still calls `_manager.__enter__`, but doesn't bind the result to any name, and still calls `_manager.__exit__` at block termination. The object returned by the *`expression`*, with methods `__enter__` and `__exit__`, is known as a *context manager*.

The **with** statement is the Python embodiment of the well-known C++ idiom "resource acquisition is initialization" (RAII): you need only write context manager classes—that is, classes with two special methods, `__enter__` and `__exit__`. `__enter__` must be callable without arguments. `__exit__` must be callable with three arguments: all **None** when the body completes without propagating exceptions, and otherwise, the type, value, and traceback of the exception. This provides the same guaranteed finalization behavior as typical `ctor/dtor` pairs have for `auto` variables in C++ and **try/finally** statements have in Python or Java. In addition, they can finalize differently depending on what exception, if any, propagates, and optionally block a propagating exception by returning a true value from `__exit__`.

For example, here is a simple, purely illustrative way to ensure `<name>` and `</name>` tags are printed around some other output (note that context manager classes often have lowercase names, rather than following the normal title case convention for class names):

```
class enclosing_tag:
    def __init__(self, tagname):
        self.tagname = tagname
    def __enter__(self):
        print(f'<{self.tagname}>', end='')
    def __exit__(self, etyp, einst, etb):
        print(f'</{self.tagname}>')

# to be used as:
with enclosing_tag('sometag'):
    # ...statements printing output to be enclosed in
    # a matched open/close `sometag` pair...
```

A simpler way to build context managers is to use the `contextmanager` decorator in the `contextlib` module of the Python standard library. This decorator turns a generator function into a factory of context manager objects.

The `contextlib` way to implement the `enclosing_tag` context manager, having imported `contextlib` earlier, is:

```
@contextlib.contextmanager
def enclosing_tag(tagname):
    print(f'<{tagname}>', end='')
    try:
        yield
    finally:
        print(f'</{tagname}>')
# to be used the same way as before
```

`contextlib` supplies, among others, the class and functions listed in Table 6-1.

Table 6-1. Commonly used classes and functions in the `contextlib` module

`AbstractContext Manager`	`AbstractContextManager` An abstract base class with two overridable methods: `__enter__`, which defaults to **`return`** `self`, and `__exit__`, which defaults to **`return`** None.
`chdir`	`chdir(`*`dir_path`*`)` **3.11+** A context manager whose `__enter__` method saves the current working directory path and performs `os.chdir(`*`dir_path`*`)`, and whose `__exit__` method performs `os.chdir(`*`saved_path`*`)`.
`closing`	`closing(`*`something`*`)` A context manager whose `__enter__` method is **`return`** *`something`*, and whose `__exit__` method calls *`something`*`.close()`.
`contextmanager`	`contextmanager` A decorator that you apply to a generator to make it into a context manager.
`nullcontext`	`nullcontext(`*`something`*`)` A context manager whose `__enter__` method is **`return`** *`something`*, and whose `__exit__` method does nothing.
`redirect_stderr`	`redirect_stderr(`*`destination`*`)` A context manager that temporarily redirects, within the body of the **`with`** statement, `sys.stderr` to the file or file-like object *`destination`*.
`redirect_stdout`	`redirect_stdout(`*`destination`*`)` A context manager that temporarily redirects, within the body of the **`with`** statement, `sys.stdout` to the file or file-like object *`destination`*.

`suppress`	`suppress(`*`*exception_classes`*`)`
	A context manager that silently suppresses exceptions occurring in the body of the **`with`** statement of any of the classes listed in *`exception_classes`*. For instance, this function to delete a file ignores `FileNotFoundError`:
	`def delete_file(filename):`
	`    with contextlib.suppress(FileNotFoundError):`
	`        os.remove(filename)`
	Use sparingly, since silently suppressing exceptions is often bad practice.

For more details, examples, "recipes," and even more (somewhat abstruse) classes, see Python's online docs.

Generators and Exceptions

To help generators cooperate with exceptions, **`yield`** statements are allowed inside **`try`**/**`finally`** statements. Moreover, generator objects have two other relevant methods, `throw` and `close`. Given a generator object *`g`* built by calling a generator function, the `throw` method's signature is:

```
g.throw(exc_value)
```

When the generator's caller calls `g.throw`, the effect is just as if a **`raise`** statement with the same argument executed at the spot of the **`yield`** at which generator *g* is suspended.

The generator method `close` has no arguments; when the generator's caller calls `g.close()`, the effect is like calling `g.throw(GeneratorExit())`.[1] `GeneratorExit` is a built-in exception class that inherits directly from `BaseException`. Generators also have a finalizer (the special method `__del__`) that implicitly calls `close` when the generator object is garbage-collected.

If a generator raises or propagates a `StopIteration` exception, Python turns the exception's type into `RuntimeError`.

Exception Propagation

When an exception is raised, the exception propagation mechanism takes control. The normal control flow of the program stops, and Python looks for a suitable exception handler. Python's **`try`** statement establishes exception handlers via its **`except`** clauses. The handlers deal with exceptions raised in the body of the **`try`** clause, as well as exceptions propagating from functions called by that code, directly or indirectly. If an exception is raised within a **`try`** clause that has an applicable **`except`** handler, the **`try`** clause terminates and the handler executes. When the handler finishes, execution continues with the statement after the **`try`** statement (in the absence of any explicit change to the flow of control, such as a **`raise`** or **`return`** statement).

If the statement raising the exception is not within a **`try`** clause that has an applicable handler, the function containing the statement terminates, and the exception propagates "upward" along the stack of function calls to the statement that called the function. If the call to the terminated function is within a **`try`** clause that has an applicable handler, that **`try`** clause terminates, and the handler executes. Otherwise, the function containing the call terminates, and the propagation process repeats, *unwinding* the stack of function calls until an applicable handler is found.

If Python cannot find any applicable handler, by default the program prints an error message to the standard error stream (`sys.stderr`). The error message includes a traceback that gives details about functions terminated during propagation. You can change Python's default error-reporting behavior by setting `sys.excepthook` (covered in Table 8-3). After error reporting, Python goes back to the interactive session, if any, or terminates if execution was not interactive. When the exception type is `SystemExit`, termination is silent and ends the interactive session, if any.

Here are some functions to show exception propagation at work:

1 Except that multiple calls to `close` are allowed and innocuous: all but the first one perform no operation.

```python
def f():
    print('in f, before 1/0')
    1/0    # raises a ZeroDivisionError exception
    print('in f, after 1/0')
def g():
    print('in g, before f()')
    f()
    print('in g, after f()')
def h():
    print('in h, before g()')
    try:
        g()
        print('in h, after g()')
    except ZeroDivisionError:
        print('ZD exception caught')
    print('function h ends')
```

Calling the `h` function prints the following:

```
in h, before g()
in g, before f()
in f, before 1/0
ZD exception caught
function h ends
```

That is, none of the "after" `print` statements execute, since the flow of exception propagation cuts them off.

The function `h` establishes a **`try`** statement and calls the function `g` within the **`try`** clause. `g`, in turn, calls `f`, which performs a division by `0`, raising an exception of type `ZeroDivisionError`. The exception propagates all the way back to the **`except`** clause in `h`. The functions `f` and `g` terminate during the exception propagation phase, which is why neither of their "after" messages is printed. The execution of `h`'s **`try`** clause also terminates during the exception propagation phase, so its "after" message isn't printed either. Execution continues after the handler, at the end of `h`'s **`try`/`except`** block.

Exceptions

Exception Objects

Exceptions are instances of `BaseException` (more specifically, instances of one of its subclasses). Table 6-2 lists the attributes and methods of `BaseException`.

Table 6-2. Attributes and methods of the `BaseException` class

`__cause__`	*`exc`*`.__cause__` Returns the parent exception of an exception raised using **`raise from`**.
`__notes__`	*`exc`*`.__notes__` **3.11+** Returns a list of `str`s added to the exception using `add_note`. This attribute only exists if `add_note` has been called at least once, so the safe way to access this list is with `getattr(`*`exc`*`, '__notes__', [])`.

add_note	*exc*.add_note(*note*) **3.11+** Appends the str *note* to the notes on this exception. These notes are shown after the traceback when displaying the exception.
args	*exc*.args Returns a tuple of the arguments used to construct the exception. This error-specific information is useful for diagnostic or recovery purposes. Some exception classes interpret args and set convenient named attributes on the classes' instances.
with_traceback	*exc*.with_traceback(*tb*) Returns a new exception, replacing the original exception's traceback with the new traceback *tb*, or with no traceback if *tb* is **None**. Can be used to trim the original traceback to remove internal library function call frames.

The Hierarchy of Standard Exceptions

As mentioned previously, exceptions are instances of subclasses of BaseException. The inheritance structure of exception classes is important, as it determines which **except** clauses handle which exceptions. Most exception classes extend the class Exception; however, the classes KeyboardInterrupt, GeneratorExit, and SystemExit inherit directly from BaseException and are not subclasses of Exception. Thus, a handler clause **except** Exception **as** e does not catch KeyboardInterrupt, GeneratorExit, or SystemExit (we covered exception handlers in "try/except" on page 196 and GeneratorExit in "Generators and Exceptions" on page 203). Instances of SystemExit are normally raised via the exit function in the sys module (covered in Table 8-3). When the user hits Ctrl-C, Ctrl-Break, or other interrupting keys on their keyboard, that raises KeyboardInterrupt.

The hierarchy of built-in exception classes is, roughly:

```
BaseException
  Exception
    AssertionError, AttributeError, BufferError, EOFError,
    MemoryError, ReferenceError, OsError, StopAsyncIteration,
    StopIteration, SystemError, TypeError
    ArithmeticError (abstract)
      OverflowError, ZeroDivisionError
    ImportError
      ModuleNotFoundError, ZipImportError
    LookupError (abstract)
      IndexError, KeyError
    NameError
      UnboundLocalError
    OSError
      ...
    RuntimeError
      RecursionError
      NotImplementedError
    SyntaxError
      IndentationError
        TabError
```

```
    ValueError
      UnsupportedOperation
      UnicodeError
        UnicodeDecodeError, UnicodeEncodeError,
        UnicodeTranslateError
    Warning
      ...
  GeneratorExit
  KeyboardInterrupt
  SystemExit
```

There are other exception subclasses (in particular, `Warning` and `OSError` have many, whose omission is indicated here with ellipses), but this is the gist. A complete list is available in Python's online docs.

The classes marked "(abstract)" are never instantiated directly; their purpose is to make it easier for you to specify **`except`** clauses that handle a range of related errors.

Standard Exception Classes

Table 6-3 lists exception classes raised by common runtime errors.

Table 6-3. Standard exception classes

Exception class	Raised when
`AssertionError`	An **`assert`** statement failed.
`AttributeError`	An attribute reference or assignment failed.
`ImportError`	An **`import`** or **`from...import`** statement (covered in "The import Statement" on page 222) couldn't find the module to import (in this case, what Python raises is actually an instance of `ImportError`'s subclass `ModuleNotFoundError`), or couldn't find a name to be imported from the module.
`IndentationError`	The parser encountered a syntax error due to incorrect indentation. Subclasses `SyntaxError`.
`IndexError`	An integer used to index a sequence is out of range (using a noninteger as a sequence index raises `TypeError`). Subclasses `LookupError`.
`KeyboardInterrupt`	The user pressed the interrupt key combination (Ctrl-C, Ctrl-Break, Delete, or others, depending on the platform's handling of the keyboard).
`KeyError`	A key used to index a mapping is not in the mapping. Subclasses `LookupError`.
`MemoryError`	An operation ran out of memory.
`NameError`	A name was referenced, but it was not bound to any variable in the current scope.
`NotImplementedError`	Raised by abstract base classes to indicate that a concrete subclass must override a method.

Exception class	Raised when
OSError	Raised by functions in the module os (covered in "The os Module" on page 343 and "Running Other Programs with the os Module" on page 478) to indicate platform-dependent errors. OSError has many subclasses, covered in the following subsection.
RecursionError	Python detected that the recursion depth has been exceeded. Subclasses RuntimeError.
RuntimeError	Raised for any error or anomaly not otherwise classified.
SyntaxError	Python's parser encountered a syntax error.
SystemError	Python has detected an error in its own code, or in an extension module. Please report this to the maintainers of your Python version, or of the extension in question, including the error message, the exact Python version (sys.version), and, if possible, your program's source code.
TypeError	An operation or function was applied to an object of an inappropriate type.
UnboundLocalError	A reference was made to a local variable, but no value is currently bound to that local variable. Subclasses NameError.
UnicodeError	An error occurred while converting Unicode (i.e., a str) to a byte string, or vice versa. Subclasses ValueError.
ValueError	An operation or function was applied to an object that has a correct type but an inappropriate value, and nothing more specific (e.g., KeyError) applies.
ZeroDivisionError	A divisor (the righthand operand of a /, //, or % operator, or the second argument to the built-in function divmod) is 0. Subclasses ArithmeticError.

OSError subclasses

OSError represents errors detected by the operating system. To handle such errors more elegantly, OSError has many subclasses, whose instances are what actually get raised; for a complete list, see Python's online docs.

For example, consider this task: try to read and return the contents of a certain file, return a default string if the file does not exist, and propagate any other exception that makes the file unreadable (except for the file not existing). Using an existing OSError subclass, you can accomplish the task quite simply:

```
def read_or_default(filepath, default):
    try:
        with open(filepath) as f:
            return f.read()
    except FileNotFoundError:
        return default
```

The FileNotFoundError subclass of OSError makes this kind of common task simple and direct to express in code.

Exceptions "wrapping" other exceptions or tracebacks

Sometimes, you cause an exception while trying to handle another. To let you clearly diagnose this issue, each exception instance holds its own traceback object; you can make another exception instance with a different traceback with the `with_traceback` method.

Moreover, Python automatically stores which exception it's handling as the `__context__` attribute of any further exception raised during the handling (unless you set the exception's `__suppress_context__` attribute to **`True`** with the **`raise...from`** statement, which we cover shortly). If the new exception propagates, Python's error message uses that exception's `__context__` attribute to show details of the problem. For example, take the (deliberately!) broken code:

```
try:
    1/0
except ZeroDivisionError:
    1+'x'
```

The error displayed is:

```
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
ZeroDivisionError: division by zero

During handling of the above exception, another exception occurred:

Traceback (most recent call last):
  File "<stdin>", line 3, in <module>
TypeError: unsupported operand type(s) for +: 'int' and 'str'
```

Thus, Python clearly displays both exceptions, the original and the intervening one.

To get more control over the error display, you can, if you wish, use the **`raise...from`** statement. When you execute **`raise`** *`e`* **`from`** *`ex`*, both *`e`* and *`ex`* are exception objects: *`e`* is the one that propagates, and *`ex`* is its "cause." Python records *`ex`* as the value of *`e.__cause__`*, and sets *`e`*`.__suppress_context__` to true. (Alternatively, *`ex`* can be **`None`**: then, Python sets *`e.__cause__`* to **`None`**, but still sets *`e`*`.__suppress_context__` to true, and thus leaves *`e`*`.__context__` alone).

As another example, here's a class implementing a mock filesystem directory using a Python dict, with the filenames as the keys and the file contents as the values:

```
class FileSystemDirectory:
    def __init__(self):
        self._files = {}

    def write_file(self, filename, contents):
        self._files[filename] = contents

    def read_file(self, filename):
        try:
            return self._files[filename]
```

Exceptions

```
        except KeyError:
            raise FileNotFoundError(filename)
```

When `read_file` is called with a nonexistent filename, the access to the `self._files` dict raises `KeyError`. Since this code is intended to emulate a filesystem directory, `read_file` catches the `KeyError` and raises `FileNotFoundError` instead.

As is, accessing a nonexistent file named `'data.txt'` will output an exception message similar to:

```
Traceback (most recent call last):
  File "C:\dev\python\faux_fs.py", line 11, in read_file
    return self._files[filename]
KeyError: 'data.txt'

During handling of the above exception, another exception occurred:

Traceback (most recent call last):
  File "C:\dev\python\faux_fs.py", line 20, in <module>
    print(fs.read_file("data.txt"))
  File "C:\dev\python\faux_fs.py", line 13, in read_file
    raise FileNotFoundError(filename)
FileNotFoundError: data.txt
```

This exception report shows both the `KeyError` and the `FileNotFoundError`. To suppress the internal `KeyError` exception (to hide implementation details of `FileSystemDirectory`), we change the **`raise`** statement in `read_file` to:

```
raise FileNotFoundError(filename) from None
```

Now the exception only shows the `FileNotFoundError` information:

```
Traceback (most recent call last):
  File "C:\dev\python\faux_fs.py", line 20, in <module>
    print(fs.read_file("data.txt"))
  File "C:\dev\python\faux_fs.py", line 13, in read_file
    raise FileNotFoundError(filename) from None
FileNotFoundError: data.txt
```

For details and motivations regarding exception chaining and embedding, see PEP 3134.

Custom Exception Classes

You can extend any of the standard exception classes in order to define your own exception class. Often, such a subclass adds nothing more than a docstring:

```
class InvalidAttributeError(AttributeError):
    """Used to indicate attributes that could never be valid."""
```

An Empty Class or Function Should Have a Docstring

As covered in "The `pass` Statement" on page 92, you don't need a `pass` statement to make up the body of a class. The docstring (which you should always write, to document the class's purpose if nothing else!) is enough to keep Python happy. Best practice for all "empty" classes (regardless of whether they are exception classes), just like for all "empty" functions, is usually to have a docstring and no **`pass`** statement.

Given the semantics of **`try/except`**, raising an instance of a custom exception class such as `InvalidAttributeError` is almost the same as raising an instance of its standard exception superclass, `AttributeError`, but with some advantages. Any **`except`** clause that can handle `AttributeError` can handle `InvalidAttributeError` just as well. In addition, client code that knows about your `InvalidAttributeError` custom exception class can handle it specifically, without having to handle all other cases of `AttributeError` when it is not prepared for those. For example, suppose you write code like the following:

```
class SomeFunkyClass:
    """much hypothetical functionality snipped"""
    def __getattr__(self, name):
        """only clarifies the kind of attribute error"""
        if name.startswith('_'):
            raise InvalidAttributeError(
                f'Unknown private attribute {name!r}'
            )
        else:
            raise AttributeError(f'Unknown attribute {name!r}')
```

Now, client code can, if it so chooses, be more selective in its handlers. For example:

```
s = SomeFunkyClass()
try:
    value = getattr(s, thename)
except InvalidAttributeError as err:
    warnings.warn(str(err), stacklevel=2)
    value = None
# other cases of AttributeError just propagate, as they're unexpected
```

Use Custom Exception Classes

It's an excellent idea to define, and raise, instances of custom exception classes in your modules, rather than plain standard exceptions. By using custom exception classes that extend standard ones, you make it easier for callers of your module's code to handle exceptions that come from your module separately from others, if they choose to.

Custom Exceptions and Multiple Inheritance

An effective approach to the use of custom exceptions is to multiply inherit exception classes from your module's special custom exception class and a standard exception class, as in the following snippet:

```
class CustomAttributeError(CustomException, AttributeError):
    """An AttributeError which is ALSO a CustomException."""
```

Now, an instance of `CustomAttributeError` can only be raised explicitly and deliberately, showing an error related specifically to your code that *also* happens to be an `AttributeError`. When your code raises an instance of `CustomAttributeError`, that exception can be caught by calling code that's designed to catch all cases of `AttributeError` as well as by code that's designed to catch all exceptions raised only, specifically, by your module.

> **Use Multiple Inheritance for Custom Exceptions**
>
> Whenever you must decide whether to raise an instance of a specific standard exception, such as `AttributeError`, or of a custom exception class you define in your module, consider this multiple inheritance approach, which, in this book's authors' opinion,[2] gives you the best of both worlds in such cases. Make sure you clearly document this aspect of your module, because the technique, although handy, is not widely used. Users of your module may not expect it unless you clearly and explicitly document what you are doing.

Other Exceptions Used in the Standard Library

Many modules in Python's standard library define their own exception classes, which are equivalent to the custom exception classes that your own modules can define. Typically, all functions in such standard library modules may raise exceptions of such classes, in addition to exceptions in the standard hierarchy covered in "Standard Exception Classes" on page 207. We cover the main cases of such exception classes throughout the rest of this book, in chapters covering the standard library modules that supply and may raise them.

ExceptionGroup and except*

3.11+ In some circumstances, such as when performing validation of some input data against multiple criteria, it is useful to be able to raise more than a single exception at once. Python 3.11 introduced a mechanism to raise multiple exceptions

2 This is somewhat controversial: while this book's authors agree on this being "best practice," some others strongly insist that one should always avoid multiple inheritance, including in this specific case.

at once using an `ExceptionGroup` instance and to process more than one exception using an **`except*`** form in place of **`except`**.

To raise `ExceptionGroup`, the validating code captures multiple `Exceptions` into a list and then raises an `ExceptionGroup` that is constructed using that list. Here is some code that searches for misspelled and invalid words, and raises an `ExceptionGroup` containing all of the found errors:

```
class GrammarError(Exception):
    """Base exception for grammar checking"""
    def __init__(self, found, suggestion):
        self.found = found
        self.suggestion = suggestion

class InvalidWordError(GrammarError):
    """Misused or nonexistent word"""

class MisspelledWordError(GrammarError):
    """Spelling error"""

invalid_words = {
    'irregardless': 'regardless',
    "ain't": "isn't",
}
misspelled_words = {
    'tacco': 'taco',
}

def check_grammar(s):
    exceptions = []
    for word in s.lower().split():
        if (suggestion := invalid_words.get(word)) is not None:
            exceptions.append(InvalidWordError(word, suggestion))
        elif (suggestion := misspelled_words.get(word)) is not None:
            exceptions.append(MisspelledWordError(word, suggestion))
    if exceptions:
        raise ExceptionGroup('Found grammar errors', exceptions)
```

The following code validates a sample text string and lists out all the found errors:

```
text = "Irregardless a hot dog ain't a tacco"
try:
    check_grammar(text)
except* InvalidWordError as iwe:
    print('\n'.join(f'{e.found!r} is not a word, use {e.suggestion!r}'
                    for e in iwe.exceptions))
except* MisspelledWordError as mwe:
    print('\n'.join(f'Found {e.found!r}, perhaps you meant'
                    f' {e.suggestion!r}?'
                    for e in mwe.exceptions))
else:
    print('No errors!')
```

giving this output:

```
'irregardless' is not a word, use 'regardless'
"ain't" is not a word, use "isn't"
Found 'tacco', perhaps you meant 'taco'?
```

Unlike **except**, after it finds an initial match, **except*** continues to look for additional exception handlers matching exception types in the raised `ExceptionGroup`.

Error-Checking Strategies

Most programming languages that support exceptions raise exceptions only in rare cases. Python's emphasis is different. Python deems exceptions appropriate whenever they make a program simpler and more robust, even if that makes exceptions rather frequent.

LBYL Versus EAFP

A common idiom in other languages, sometimes known as "look before you leap" (LBYL), is to check in advance, before attempting an operation, for anything that might make the operation invalid. This approach is not ideal, for several reasons:

- The checks may diminish the readability and clarity of the common, mainstream cases where everything is OK.
- The work needed for checking purposes may duplicate a substantial part of the work done in the operation itself.
- The programmer might easily err by omitting a needed check.
- The situation might change between the moment when you perform the checks and the moment when, later (even by a tiny fraction of a second!), you attempt the operation.

The preferred idiom in Python is to attempt the operation in a **try** clause and handle the exceptions that may result in one or more **except** clauses. This idiom is known as "It's easier to ask forgiveness than permission" (EAFP), a frequently quoted motto widely credited to Rear Admiral Grace Murray Hopper, co-inventor of COBOL. EAFP shares none of the defects of LBYL. Here is a function using the LBYL idiom:

```python
def safe_divide_1(x, y):
    if y==0:
        print('Divide-by-0 attempt detected')
        return None
    else:
        return x/y
```

With LBYL, the checks come first, and the mainstream case is somewhat hidden at the end of the function.

Here is the equivalent function using the EAFP idiom:

```
def safe_divide_2(x, y):
    try:
        return x/y
    except ZeroDivisionError:
        print('Divide-by-0 attempt detected')
        return None
```

With EAFP, the mainstream case is up front in a **try** clause, and the anomalies are handled in the following **except** clause, making the whole function easier to read and understand.

EAFP is a good error-handling strategy, but it is not a panacea. In particular, you must take care not to cast too wide a net, catching errors that you did not expect and therefore did not mean to catch. The following is a typical case of such a risk (we cover built-in function `getattr` in Table 8-2):

```
def trycalling(obj, attrib, default, *args, **kwds):
    try:
        return getattr(obj, attrib)(*args, **kwds)
    except AttributeError:
        return default
```

The intention of the `trycalling` function is to try calling a method named *`attrib`* on the object *`obj`*, but to return *`default`* if *`obj`* has no method thus named. However, the function as coded does not do *just* that: it also accidentally hides any error case where an `AttributeError` is raised inside the sought-after method, silently returning *`default`* in those cases. This could easily hide bugs in other code. To do exactly what's intended, the function must take a little bit more care:

```
def trycalling(obj, attrib, default, *args, **kwds):
    try:
        method = getattr(obj, attrib)
    except AttributeError:
        return default
    else:
        return method(*args, **kwds)
```

This implementation of `trycalling` separates the `getattr` call, placed in the **try** clause and therefore guarded by the handler in the **except** clause, from the call of the method, placed in the **else** clause and therefore free to propagate any exception. The proper approach to EAFP involves frequent use of the **else** clause in **try/except** statements (which is more explicit, and thus better Python style, than just placing the nonguarded code after the whole **try/except** statement).

Handling Errors in Large Programs

In large programs, it is especially easy to err by making your **try/except** statements too broad, particularly once you have convinced yourself of the power of EAFP as a general error-checking strategy. A **try/except** combination is too broad when it catches too many different errors, or an error that can occur in too many different places. The latter is a problem when you need to distinguish exactly what went wrong and where, and the information in the traceback is not sufficient to pinpoint such details (or you discard some or all of the information in the traceback). For effective error handling, you have to keep a clear distinction between errors and anomalies that you expect (and thus know how to handle) and unexpected errors and anomalies that may indicate a bug in your program.

Some errors and anomalies are not really erroneous, and perhaps not even all that anomalous: they are just special "edge" cases, perhaps somewhat rare but nevertheless quite expected, which you choose to handle via EAFP rather than via LBYL to avoid LBYL's many intrinsic defects. In such cases, you should just handle the anomaly, often without even logging or reporting it.

Keep Your try/except Constructs Narrow

Be very careful to keep **`try/except`** constructs as narrow as feasible. Use a small **`try`** clause that contains a small amount of code that doesn't call too many other functions, and use very specific exception class tuples in the **`except`** clauses. If need be, further analyze the details of the exception in your handler code, and **`raise`** again as soon as you know it's not a case this handler can deal with.

Errors and anomalies that depend on user input or other external conditions not under your control are always expected, precisely because you have no control over their underlying causes. In such cases, you should concentrate your effort on handling the anomaly gracefully, reporting and logging its exact nature and details, and keeping your program running with undamaged internal and persistent state. Your **`try/except`** clauses should still be reasonably narrow, although this is not quite as crucial as when you use EAFP to structure your handling of not-really-erroneous special/edge cases.

Lastly, entirely unexpected errors and anomalies indicate bugs in your program's design or coding. In most cases, the best strategy regarding such errors is to avoid **`try/except`** and just let the program terminate with error and traceback messages. (You might want to log such information and/or display it more suitably with an application-specific hook in `sys.excepthook`, as we'll discuss shortly.) In the unlikely case that your program must keep running at all costs, even under dire circumstances, **`try/except`** statements that are quite wide may be appropriate, with the **`try`** clause guarding function calls that exercise vast swaths of program functionality, and broad **`except`** clauses.

In the case of a long-running program, make sure to log all details of the anomaly or error to some persistent place for later study (and also report to yourself some indication of the problem, so that you know such later study is necessary). The key is making sure that you can revert the program's persistent state to some undamaged, internally consistent point. The techniques that enable long-running programs to survive some of their own bugs, as well as environmental adversities, are known as checkpointing (basically, periodically saving program state, and writing the program so it can reload the saved state and continue from there) and transaction processing; we do not cover them further in this book.

Logging Errors

When Python propagates an exception all the way to the top of the stack without finding an applicable handler, the interpreter normally prints an error traceback to the standard error stream of the process (`sys.stderr`) before terminating the program. You can rebind `sys.stderr` to any file-like object usable for output in order to divert this information to a destination more suitable for your purposes.

When you want to change the amount and kind of information output on such occasions, rebinding `sys.stderr` is not sufficient. In such cases, you can assign your own function to `sys.excepthook`: Python calls it when terminating the program due to an unhandled exception. In your exception-reporting function, output whatever information will help you diagnose and debug the problem and direct that information to whatever destinations you please. For example, you might use the `traceback` module (covered in "The traceback Module" on page 533) to format stack traces. When your exception-reporting function terminates, so does your program.

The logging module

The Python standard library offers the rich and powerful `logging` module to let you organize the logging of messages from your applications in systematic, flexible ways. Pushing things to the limit, you might write a whole hierarchy of `Logger` classes and subclasses; you could couple the loggers with instances of `Handler` (and subclasses thereof), or insert instances of the class `Filter` to fine-tune criteria determining what messages get logged in which ways.

Exceptions

Messages are formatted by instances of the `Formatter` class—the messages themselves are instances of the `LogRecord` class. The `logging` module even includes a dynamic configuration facility, whereby you may dynamically set logging configuration files by reading them from disk files, or even by receiving them on a dedicated socket in a specialized thread.

While the `logging` module sports a frighteningly complex and powerful architecture, suitable for implementing highly sophisticated logging strategies and policies that may be needed in vast and complicated software systems, in most applications you might get away with using a tiny subset of the package. First, **`import`** `logging`. Then, emit your message by passing it as a string to any of the module's functions `debug`, `info`, `warning`, `error`, or `critical`, in increasing order of severity. If the string you pass contains format specifiers such as `%s` (as covered in "Legacy String Formatting with %" on page 297), then, after the string, pass as further arguments all the values to be formatted in that string. For example, don't call:

```
logging.debug('foo is %r' % foo)
```

which performs the formatting operation whether it's needed or not; rather, call:

```
logging.debug('foo is %r', foo)
```

which performs formatting if and only if needed (i.e., if and only if calling debug is going to result in logging output, depending on the current threshold logging level). If `foo` is used only for logging and is especially compute- or I/O-intensive to create, you can use `isEnabledFor` to conditionalize the expensive code that creates `foo`:

```
if logging.getLogger().isEnabledFor(logging.DEBUG):
    foo = cpu_intensive_function()
    logging.debug('foo is %r', foo)
```

Configuring logging

Unfortunately, the `logging` module does not support the more readable formatting approaches covered in "String Formatting" on page 287, but only the legacy one mentioned in the previous subsection. Fortunately, it's very rare to need any formatting specifiers beyond `%s` (which calls `__str__`) and `%r` (which calls `__repr__`).

By default, the threshold level is `WARNING`: any of the functions `warning`, `error`, or `critical` results in logging output, but the functions `debug` and `info` do not. To change the threshold level at any time, call `logging.getLogger().setLevel`, passing as the only argument one of the corresponding constants supplied by the `logging` module: `DEBUG`, `INFO`, `WARNING`, `ERROR`, or `CRITICAL`. For example, once you call:

```
logging.getLogger().setLevel(logging.DEBUG)
```

all of the logging functions from `debug` to `critical` result in logging output until you change the level again. If later you call:

```
logging.getLogger().setLevel(logging.ERROR)
```

then only the functions `error` and `critical` result in logging output (`debug`, `info`, and `warning` won't result in logging output); this condition, too, persists until you change the level again, and so forth.

By default, logging output goes to your process's standard error stream (`sys.stderr`, as covered in Table 8-3) and uses a rather simplistic format (for example, it does not include a timestamp on each line it outputs). You can control these settings by instantiating an appropriate handler instance, with a suitable formatter instance, and creating and setting a new logger instance to hold it. In the simple, common case in which you just want to set these logging parameters once and for all, after which they persist throughout the run of your program, the simplest approach is to call the `logging.basicConfig` function, which lets you set things up quite simply via named parameters. Only the very first call to `logging.basicConfig` has any effect, and only if you call it before any of the logging functions (`debug`, `info`, and so on). Therefore, the most common use is to call `logging.basicConfig` at the very start of your program. For example, a common idiom at the start of a program is something like:

```
import logging
logging.basicConfig(
    format='%(asctime)s %(levelname)8s %(message)s',
    filename='/tmp/logfile.txt', filemode='w')
```

This setting writes logging messages to a file, nicely formatted with a precise human-readable timestamp, followed by the severity level right-aligned in an eight-character field, followed by the message proper.

For much, much more detailed information on the `logging` module and all the wonders you can perform with it, be sure to consult Python's rich online documentation.

The assert Statement

The **`assert`** statement allows you to introduce "sanity checks" into a program. **`assert`** is a simple statement with the following syntax:

```
assert condition[, expression]
```

When you run Python with the optimize flag (**`-O`**, as covered in "Command-Line Syntax and Options" on page 22), **`assert`** is a null operation: the compiler generates no code for it. Otherwise, **`assert`** evaluates *`condition`*. When *`condition`* is satisfied, **`assert`** does nothing. When *`condition`* is not satisfied, **`assert`** instantiates `AssertionError` with *`expression`* as the argument (or without arguments, if there is no *`expression`*) and raises the resulting instance.[3]

`assert` statements can be an effective way to document your program. When you want to state that a significant, nonobvious condition *`C`* is known to hold at a certain point in a program's execution (known as an *invariant* of your program), **`assert`** *`C`* is often better than a comment that just states that *`C`* holds.

Don't Overuse assert

Never use **`assert`** for other purposes besides sanity-checking program invariants. A serious but very common mistake is to use **`assert`** about the values of inputs or arguments. Checking for erroneous arguments or inputs is best done more explicitly, and in particular must not be done using **`assert`**, since it can be turned into a null operation by a Python command-line flag.

3 Some third-party frameworks, such as `pytest`, materially improve the usefulness of the **`assert`** statement.

The advantage of **assert** is that, when *C* does *not* in fact hold, **assert** immediately alerts you to the problem by raising `AssertionError`, if the program is running without the **-O** flag. Once the code is thoroughly debugged, run it with **-O**, turning **assert** into a null operation and incurring no overhead (the **assert** remains in your source code to document the invariant).

The __debug__ Built-in Variable

When you run Python without the option **-O**, the `__debug__` built-in variable is **True**. When you run Python with the option **-O**, `__debug__` is **False**. Also, in the latter case the compiler generates no code for any **if** statement whose sole guard condition is `__debug__`.

To exploit this optimization, surround the definitions of functions that you call only in **assert** statements with **if** `__debug__`**:**. This technique makes compiled code smaller and faster when Python is run with **-O**, and enhances program clarity by showing that those functions exist only to perform sanity checks.

7
Modules and Packages

A typical Python program is made up of several source files. Each source file is a *module*, grouping code and data for reuse. Modules are normally independent of each other, so that other programs can reuse the specific modules they need. Sometimes, to manage complexity, developers group together related modules into a *package*—a hierarchical, tree-like structure of related modules and subpackages.

A module explicitly establishes dependencies upon other modules by using **`import`** or **`from`** statements. In some programming languages, global variables provide a hidden conduit for coupling between modules. In Python, global variables are not global to all modules, but rather are attributes of a single module object. Thus, Python modules always communicate in explicit and maintainable ways, clarifying the couplings between them by making them explicit.

Python also supports *extension modules*—modules coded in other languages such as C, C++, Java, C#, or Rust. For the Python code importing a module, it does not matter whether the module is pure Python or an extension. You can always start by coding a module in Python. Should you need more speed later, you can refactor and recode some parts of your module in lower-level languages, without changing the client code that uses the module. Chapter 25 (available online) shows how to write extensions in C and Cython.

This chapter discusses module creation and loading. It also covers grouping modules into packages, using `setuptools` to install packages, and how to prepare packages for distribution; this latter subject is more thoroughly covered in Chapter 24 (also available online). We close this chapter with a discussion of how best to manage your Python environment(s) .

Module Objects

In Python, a module is an object with arbitrarily named attributes that you can bind and reference. Modules in Python are handled like other objects. Thus, you can pass a module as an argument in a call to a function. Similarly, a function can return a module as the result of a call. A module, just like any other object, can be bound to a variable, an item in a container, or an attribute of an object. Modules can be keys or values in a dictionary, and can be members of a set. For example, the `sys.modules` dictionary, discussed in "Module Loading" on page 227, holds module objects as its values. The fact that modules can be treated like other values in Python is often expressed by saying that modules are *first-class* objects.

The import Statement

The Python code for a module named *aname* usually lives in a file named *aname.py*, as covered in "Searching the Filesystem for a Module" on page 228. You can use any Python source file[1] as a module by executing an **import** statement in another Python source file. **import** has the following syntax:

```
import modname [as varname][,...]
```

After the **import** keyword come one or more module specifiers separated by commas. In the simplest, most common case, a module specifier is just *modname*, an identifier—a variable that Python binds to the module object when the **import** statement finishes. In this case, Python looks for the module of the same name to satisfy the **import** request. For example, this statement:

```
import mymodule
```

looks for the module named `mymodule` and binds the variable named `mymodule` in the current scope to the module object. *modname* can also be a sequence of identifiers separated by dots (`.`) to name a module contained in a package, as covered in "Packages" on page 233.

When **as** *varname* is part of a module specifier, Python looks for a module named *modname* and binds the module object to the variable *varname*. For example, this:

```
import mymodule as alias
```

looks for the module named `mymodule` and binds the module object to the variable *alias* in the current scope. *varname* must always be a simple identifier.

The module body

The *body* of a module is the sequence of statements in the module's source file. There is no special syntax required to indicate that a source file is a module; as mentioned previously, you can use any valid Python source file as a module. A

1 One of our tech reviewers reports that *.pyw* files on Windows are an exception to this.

module's body executes immediately the first time a given run of a program imports it. When the body starts executing, the module object has already been created, with an entry in `sys.modules` already bound to the module object. The module's (global) namespace is gradually populated as the module's body executes.

Attributes of module objects

An **`import`** statement creates a new namespace containing all the attributes of the module. To access an attribute in this namespace, use the name or alias of the module as a prefix:

```
import mymodule
a = mymodule.f()
```

or:

```
import mymodule as alias
a = alias.f()
```

This reduces the time it takes to import the module and ensures that only those applications that use that module incur the overhead of creating it.

Normally, it is the statements in the module body that bind the attributes of a module object. When a statement in the module body binds a (global) variable, what gets bound is an attribute of the module object.

> **A Module Body Exists to Bind the Module's Attributes**
>
> The normal purpose of a module body is to create the module's attributes: **`def`** statements create and bind functions, **`class`** statements create and bind classes, and assignment statements can bind attributes of any type. For clarity and cleanliness in your code, be wary about doing anything else in the top logical level of the module's body *except* binding the module's attributes.

A `__getattr__` function defined at module scope can dynamically create new module attributes. One possible reason for doing so would be to lazily define attributes that are time-consuming to create; defining them in a module-level `__getattr__` function defers the creation of the attributes until they are actually referenced, if ever. For instance, this code could be added to *mymodule.py* to defer the creation of a list containing the first million prime numbers, which can take some time to compute:

```
def __getattr__(name):
    if name == 'first_million_primes':
        def generate_n_primes(n):
            # ... code to generate 'n' prime numbers ...

        import sys
        # Look up __name__ in sys.modules to get current module
```

```
            this_module = sys.modules[__name__]
            this_module.first_million_primes = generate_n_primes(1_000_000)
            return this_module.first_million_primes

        raise AttributeError(f'module {__name__!r}'
                             f' has no attribute {name!r}')
```

Using a module-level `__getattr__` function has only a small impact on the time to import *mymodule.py*, and only those applications that actually use `mymodule.first_million_primes` will incur the overhead of creating it.

You can also bind module attributes in code outside the body (i.e., in other modules); just assign a value to the attribute reference syntax *`M.name`* (where *`M`* is any expression whose value is the module, and the identifier *`name`* is the attribute name). For clarity, however, it's best to bind module attributes only in the module's own body.

The **`import`** statement binds some module attributes as soon as it creates the module object, before the module's body executes. The `__dict__` attribute is the `dict` object that the module uses as the namespace for its attributes. Unlike other attributes of the module, `__dict__` is not available to code in the module as a global variable. All other attributes in the module are items in `__dict__` and are available to code in the module as global variables. The `__name__` attribute is the module's name, and `__file__` is the filename from which the module was loaded; other dunder-named attributes hold other module metadata. (See also "Special Attributes of Package Objects" on page 234 for details on the attribute `__path__`, in packages only.)

For any module object *`M`*, any object *`x`*, and any identifier string *`S`* (except `__dict__`), binding *`M.S`* `=` *`x`* is equivalent to binding *`M.`*`__dict__['`*`S`*`']` `=` *`x`*. An attribute reference such as *`M.S`* is also substantially equivalent to *`M.__dict__`*`['`*`S`*`']`. The only difference is that, when *`S`* is not a key in *`M.`*`__dict__`, accessing *`M.`*`__dict__['`*`S`*`']` raises `KeyError`, while accessing *`M.S`* raises `AttributeError`. Module attributes are also available to all code in the module's body as global variables. In other words, within the module body, *`S`* used as a global variable is equivalent to *`M.S`* (i.e., *`M.`*`__dict__['`*`S`*`']`) for both binding and reference (when *`S`* is *not* a key in *`M.`*`__dict__`, however, referring to *`S`* as a global variable raises `NameError`).

Python built-ins

Python supplies many built-in objects (covered in Chapter 8). All built-in objects are attributes of a preloaded module named `builtins`. When Python loads a module, the module automatically gets an extra attribute named `__builtins__`, which refers either to the module `builtins` or to its dictionary. Python may choose either, so don't rely on `__builtins__`. If you need to access the module `builtins` directly (a rare need), use an **`import`** `builtins` statement. When you access a variable found neither in the local namespace nor in the global namespace of the current module, Python looks for the identifier in the current module's `__builtins__` before raising `NameError`.

The lookup is the only mechanism that Python uses to let your code access built-ins. Your own code can use the access mechanism directly (do so in moderation, however, or your program's clarity and simplicity will suffer). The built-ins' names are not reserved, nor are they hardwired in Python itself—you can add your own built-ins or substitute your functions for the normal built-in ones, in which case all modules see the added or replaced ones. Since Python accesses built-ins only when it cannot resolve a name in the local or module namespace, it is usually sufficient to define a replacement in one of those namespaces. The following toy example shows how you can wrap a built-in function with your own function, allowing `abs` to take a string argument (and return a rather arbitrary mangling of the string):

```
# abs takes a numeric argument; let's make it accept a string as well
import builtins
_abs = builtins.abs                      # save original built-in
def abs(str_or_num):
    if isinstance(str_or_num, str):      # if arg is a string
        return ''.join(sorted(set(str_or_num)))  # get this instead
    return _abs(str_or_num)              # call real built-in
builtins.abs = abs                       # override built-in w/wrapper
```

Module documentation strings

If the first statement in the module body is a string literal, Python binds that string as the module's documentation string attribute, named `__doc__`. For more information on documentation strings, see "Docstrings" on page 99.

Module-private variables

No variable of a module is truly private. However, by convention, every identifier starting with a single underscore (_), such as `_secret`, is *meant* to be private. In other words, the leading underscore communicates to client-code programmers that they should not access the identifier directly.

Development environments and other tools rely on the leading underscore naming convention to discern which attributes of a module are public (i.e., part of the module's interface) and which are private (i.e., to be used only within the module).

Respect the "Leading Underscore Means Private" Convention

It's important to respect the convention that a leading underscore means private, particularly when you write client code that uses modules written by others. Avoid using any attributes in such modules whose names start with _. Future releases of the modules will strive to maintain their public interface, but are quite likely to change private implementation details: private attributes are meant exactly for such details.

The from Statement

Python's **from** statement lets you import specific attributes from a module into the current namespace. **from** has two syntax variants:

```
from modname import attrname [as varname][,...]
from modname import *
```

A **from** statement specifies a module name, followed by one or more attribute specifiers separated by commas. In the simplest and most common case, an attribute specifier is just an identifier *attrname*, which is a variable that Python binds to the attribute of the same name in the module named *modname*. For example:

```
from mymodule import f
```

modname can also be a sequence of identifiers separated by dots (`.`) to name a module within a package, as covered in "Packages" on page 233.

When **as** *varname* is part of an attribute specifier, Python gets the value of the attribute *attrname* from the module and binds it to the variable *varname*. For example:

```
from mymodule import f as foo
```

attrname and *varname* are always simple identifiers.

You may optionally enclose in parentheses all the attribute specifiers that follow the keyword **import** in a **from** statement. This can be useful when you have many attribute specifiers, in order to split the single logical line of the **from** statement into multiple logical lines more elegantly than by using backslashes (`\`):

```
from some_module_with_a_long_name import (
    another_name, and_another as x, one_more, and_yet_another as y)
```

from...import *

Code that is directly inside a module body (not in the body of a function or class) may use an asterisk (`*`) in a **from** statement:

```
from mymodule import *
```

The `*` requests that "all" attributes of module *modname* be bound as global variables in the importing module. When module *modname* has an attribute named `__all__`, the attribute's value is the list of the attribute names that this type of **from** statement binds. Otherwise, this type of **from** statement binds all attributes of *modname* except those beginning with underscores.

> **Beware Using "from M import *" in Your Code**
>
> Since `from M import *` may bind an arbitrary set of global variables, it can have unforeseen, undesired side effects, such as hiding built-ins and rebinding variables you still need. Use the `*` form of `from` very sparingly, if at all, and only to import modules that are explicitly documented as supporting such usage. Your code is most likely better off *never* using this form, which is meant mostly as a convenience for occasional use in interactive Python sessions.

from versus import

The `import` statement is often a better choice than the `from` statement. When you always access module *M* with the statement `import M`, and always access *M*'s attributes with the explicit syntax `M.A`, your code is slightly less concise but far clearer and more readable. One good use of `from` is to import specific modules from a package, as we discuss in "Packages" on page 233. In most other cases, `import` is better style than `from`.

Handling import failures

If you are importing a module that is not part of standard Python and wish to handle import failures, you can do so by catching the `ImportError` exception. For instance, if your code does optional output formatting using the third-party `rich` module, but falls back to regular output if that module has not been installed, you would import the module using:

```
try:
    import rich
except ImportError:
    rich = None
```

Then, in the output portion of your program, you would write:

```
if rich is not None:
        ... output using rich module features ...
else:
        ... output using normal print() statements ...
```

Module Loading

Module-loading operations rely on attributes of the built-in `sys` module (covered in "The sys Module" on page 259) and are implemented in the built-in function `__import__`. Your code could call `__import__` directly, but this is strongly discouraged in modern Python; rather, `import importlib` and call `importlib.import_module` with the module name string as the argument. `import_module` returns the module object or, should the import fail, raises `ImportError`. However, it's best to have a clear understanding of the semantics of `__import__`, because `import_module` and `import` statements both depend on it.

To import a module named *M*, `__import__` first checks the dictionary `sys.modules`, using the string *M* as the key. When the key *M* is in the dictionary, `__import__` returns the corresponding value as the requested module object. Otherwise, `__import__` binds `sys.modules[M]` to a new empty module object with a `__name__` of *M*, then looks for the right way to initialize (load) the module, as covered in the upcoming section on searching the filesystem for a module.

Thanks to this mechanism, the relatively slow loading operation takes place only the first time a module is imported in a given run of the program. When a module is imported again, the module is not reloaded, since `__import__` rapidly finds and returns the module's entry in `sys.modules`. Thus, all imports of a given module after the first one are very fast: they're just dictionary lookups. (To *force* a reload, see "Reloading Modules" on page 230.)

Built-in Modules

When a module is loaded, `__import__` first checks whether the module is a built-in. The tuple `sys.builtin_module_names` names all built-in modules, but rebinding that tuple does not affect module loading. When it loads a built-in module, as when it loads any other extension, Python calls the module's initialization function. The search for built-in modules also looks for modules in platform-specific locations, such as the Registry in Windows.

Searching the Filesystem for a Module

If module *M* is not a built-in, `__import__` looks for *M*'s code as a file on the filesystem. `__import__` looks at the items of the list `sys.path`, which are strings, in order. Each item is the path of a directory, or the path of an archive file in the popular ZIP format. `sys.path` is initialized at program startup, using the environment variable `PYTHONPATH` (covered in "Environment Variables" on page 22), if present. The first item in `sys.path` is always the directory from which the main program is loaded. An empty string in `sys.path` indicates the current directory.

Your code can mutate or rebind `sys.path`, and such changes affect which directories and ZIP archives `__import__` searches to load modules. Changing `sys.path` does *not* affect modules that are already loaded (and thus already recorded in `sys.modules`).

If there is a text file with the extension *.pth* in the `PYTHONHOME` directory at startup, Python adds the file's contents to `sys.path`, one item per line. *.pth* files can contain blank lines and comment lines starting with the character `#`; Python ignores any such lines. *.pth* files can also contain **`import`** statements (which Python executes before your program starts to execute), but no other kinds of statements.

When looking for the file for module *M* in each directory and ZIP archive along `sys.path`, Python considers the following extensions in this order:

1. *.pyd* and *.dll* (Windows) or *.so* (most Unix-like platforms), which indicate Python extension modules. (Some Unix dialects use different extensions; e.g., *.sl* on HP-UX.) On most platforms, extensions cannot be loaded from a ZIP archive—only source or bytecode-compiled Python modules can.
2. *.py*, which indicates Python source modules.
3. *.pyc*, which indicates bytecode-compiled Python modules.
4. When it finds a *.py* file, Python also looks for a directory called *__pycache__*. If it finds such a directory, Python looks in that directory for the extension *.<tag>.pyc*, where *<tag>* is a string specific to the version of Python that is looking for the module.

One last path in which Python looks for the file for module `M` is *M/__init__.py*: a file named *__init__.py* in a directory named *M*, as covered in "Packages" on page 233.

Upon finding the source file *M.py*, Python compiles it to *M.<tag>.pyc*, unless the bytecode file is already present, is newer than *M.py*, and was compiled by the same version of Python. If *M.py* is compiled from a writable directory, Python creates a *__pycache__* subdirectory if necessary and saves the bytecode file to the filesystem in that subdirectory so that future runs won't needlessly recompile it. When the bytecode file is newer than the source file (based on an internal timestamp in the bytecode file, not on trusting the date as recorded in the filesystem), Python does not recompile the module.

Once Python has the bytecode, whether built anew by compilation or read from the filesystem, Python executes the module body to initialize the module object. If the module is an extension, Python calls the module's initialization function.

Be Careful About Naming Your Project's .py Files

A common problem for beginners occurs when programmers writing their first few projects accidentally name one of their *.py* files with the same name as an imported package, or a module in the standard library (stdlib). For example, an easy mistake when learning the `turtle` module is to name your program *turtle.py*. When Python then tries to import the `turtle` module from the stdlib, it will load the local module instead, and usually raise some unexpected `AttributeError`s shortly thereafter (since the local module does not include all the classes, functions, and variables defined in the stdlib module). Do not name your project *.py* files the same as imported or stdlib modules!

You can check whether a module name already exists using a command of the form **`python -m testname`**. If the message `'no module testname'` is displayed, then you should be safe to name your module *testname.py*.

In general, as you become familiar with the modules in the stdlib and common package names, you will come to know what names to avoid.

The Main Program

Execution of a Python application starts with a top-level script (known as the *main program*), as explained in "The python Program" on page 21. The main program executes like any other module being loaded, except that Python keeps the bytecode in memory, not saving it to disk. The module name for the main program is `'__main__'`, both as the `__name__` variable (module attribute) and as the key in `sys.modules`.

Don't Import the .py File You're Using as the Main Program

You should not import the same *.py* file that is the main program. If you do, Python loads the module again, and the body executes again in a separate module object with a different `__name__`.

Code in a Python module can test if the module is being used as the main program by checking if the global variable `__name__` has the value `'__main__'`. The idiom:

```
if __name__ == '__main__':
```

is often used to guard some code so that it executes only when the module runs as the main program. If a module is meant only to be imported, it should normally execute unit tests when run as the main program, as covered in "Unit Testing and System Testing" on page 514.

Reloading Modules

Python loads a module only the first time you import the module during a program run. When you develop interactively, you need to *reload* your modules after editing them (some development environments provide automatic reloading).

To reload a module, pass the module object (*not* the module name) as the only argument to the function `reload` from the `importlib` module. `importlib.reload(M)` ensures the reloaded version of *M* is used by client code that relies on `import M` and accesses attributes with the syntax *M.A*. However, `importlib.reload(M)` has no effect on other existing references bound to previous values of *M*'s attributes (e.g., with a **from** statement). In other words, already-bound variables remain bound as they were, unaffected by `reload`. `reload`'s inability to rebind such variables is a further incentive to use **import** rather than **from**.

`reload` is not recursive: when you reload module *M*, this does not imply that other modules imported by *M* get reloaded in turn. You must reload, by explicit calls to `reload`, every module you have modified. Be sure to take into account any module reference dependencies, so that reloads are done in the proper order.

Circular Imports

Python lets you specify circular imports. For example, you can write a module *a.py* that contains **`import`** `b`, while module *b.py* contains **`import`** `a`.

If you decide to use a circular import for some reason, you need to understand how circular imports work in order to avoid errors in your code.

> **Avoid Circular Imports**
>
> In practice, you are nearly always better off avoiding circular imports, since circular dependencies are fragile and hard to manage.

Say that the main script executes **`import`** `a`. As discussed earlier, this **`import`** statement creates a new empty module object as `sys.modules['a']`, then the body of module `a` starts executing. When `a` executes **`import`** `b`, this creates a new empty module object as `sys.modules['b']`, and then the body of module `b` starts executing. `a`'s module body cannot proceed until `b`'s module body finishes.

Now, when `b` executes **`import`** `a`, the **`import`** statement finds `sys.modules['a']` already bound, and therefore binds global variable `a` in module `b` to the module object for module `a`. Since the execution of `a`'s module body is currently blocked, module `a` is usually only partly populated at this time. Should the code in `b`'s module body try to access some attribute of module `a` that is not yet bound, an error results.

If you keep a circular import, you must carefully manage the order in which each module binds its own globals, imports other modules, and accesses globals of other modules. You get greater control over the sequence in which things happen by grouping your statements into functions, and calling those functions in a controlled order, rather than just relying on sequential execution of top-level statements in module bodies. Removing circular dependencies (for example, by moving an import away from module scope and into a referencing function) is easier than ensuring bombproof ordering to deal with circular dependencies.

> **sys.modules Entries**
>
> `__import__` never binds anything other than a module object as a value in `sys.modules`. However, if `__import__` finds an entry already in `sys.modules`, it returns that value, whatever type it may be. **`import`** and **`from`** statements rely on `__import__`, so they too can use objects that are not modules.

Custom Importers

Another advanced, rarely needed functionality that Python offers is the ability to change the semantics of some or all **`import`** and **`from`** statements.

Rebinding __import__

You can rebind the `__import__` attribute of the `builtin` module to your own custom importer function—for example, one using the generic built-in-wrapping technique shown in "Python built-ins" on page 224. Such a rebinding affects all **`import`** and **`from`** statements that execute after the rebinding and thus can have an undesired global impact. A custom importer built by rebinding `__import__` must implement the same interface and semantics as the built-in `__import__`, and, in particular, it is responsible for supporting the correct use of `sys.modules`.

Avoid Rebinding the Built-in __import__

While rebinding `__import__` may initially look like an attractive approach, in most cases where custom importers are necessary, you're better off implementing them via *import hooks* (discussed next).

Import hooks

Python offers rich support for selectively changing the details of imports' behavior. Custom importers are an advanced and rarely called for technique, yet some applications may need them for purposes such as importing code from archives other than ZIP files, databases, network servers, and so on.

The most suitable approach for such highly advanced needs is to record *importer factory* callables as items in the `meta_path` and/or `path_hooks` attributes of the module `sys`, as detailed in PEP 451. This is how Python hooks up the standard library module `zipimport` to allow seamless importing of modules from ZIP files, as previously mentioned. A full study of the details of PEP 451 is indispensable for any substantial use of `sys.path_hooks` and friends, but here's a toy-level example to help understand the possibilities, should you ever need them.

Suppose that, while developing the first outline of some program, we want to be able to use **`import`** statements for modules that we haven't written yet, getting just messages (and empty modules) as a consequence. We can obtain such functionality (leaving aside the complexities connected with packages, and dealing with simple modules only) by coding a custom importer module as follows:

```
import sys, types
class ImporterAndLoader:
     """importer and loader can be a single class"""
     fake_path = '!dummy!'
     def __init__(self, path):
         # only handle our own fake-path marker
         if path != self.fake_path:
             raise ImportError
     def find_module(self, fullname):
         # don't even try to handle any qualified module name
         if '.' in fullname:
             return None
```

```
            return self
        def create_module(self, spec):
            # returning None will have Python fall back and
            # create the module "the default way"
            return None
        def exec_module(self, mod):
            # populate the already initialized module
            # just print a message in this toy example
            print(f'NOTE: module {mod!r} not yet written')
    sys.path_hooks.append(ImporterAndLoader)
    sys.path.append(ImporterAndLoader.fake_path)
    if __name__ == '__main__':      # self-test when run as main script
        import missing_module       # importing a simple *missing* module
        print(missing_module)       # ...should succeed
        print(sys.modules.get('missing_module'))  # ...should also succeed
```

We just wrote trivial versions of `create_module` (which in this case just returns `None`, asking the system to create the module object in the "default way") and `exec_module` (which receives the module object already initialized with dunder attributes, and whose task would normally be to populate it appropriately).

We could, alternatively, have used the powerful new *module spec* concept, as detailed in PEP 451. However, that requires the standard library module `importlib`; for this toy example, we don't need all that extra power. Therefore, we chose instead to implement the method `find_module`, which, although now deprecated, still works fine for backward compatibility.

Packages

As mentioned at the beginning of this chapter, a *package* is a module containing other modules. Some or all of the modules in a package may be *subpackages*, resulting in a hierarchical tree-like structure. A package named `P` typically resides in a subdirectory, also called *P*, of some directory in `sys.path`. Packages can also live in ZIP files; in this section we explain the case in which the package lives on the filesystem, but the case in which a package is in a ZIP file is similar, relying on the hierarchical filesystem-like structure within the ZIP file.

The module body of `P` is in the file *P/__init__.py*. This file *must* exist (except in the case of namespace packages, described in PEP 420), even if it's empty (representing an empty module body), in order to tell Python that directory *P* is indeed a package. Python loads the module body of a package when you first import the package (or any of the package's modules), just like with any other Python module. The other *.py* files in the directory *P* are the modules of package `P`. Subdirectories of *P* containing *__init__.py* files are subpackages of `P`. Nesting can proceed to any depth.

You can import a module named `M` in package `P` as `P.M`. More dots let you navigate a hierarchical package structure. (A package's module body always loads *before* any module in the package.) If you use the syntax **`import P.M`**, the variable `P` is bound to the module object of package `P`, and the attribute `M` of object `P` is bound to the

Modules and Packages

module `P.M`. If you use the syntax **`import`** `P.M` as `V`, the variable `V` is bound directly to the module `P.M`.

Using **`from`** `P` **`import`** `M` to import a specific module `M` from package `P` is a perfectly acceptable and indeed highly recommended practice: the **`from`** statement is specifically OK in this case. **`from`** `P` **`import`** `M` **`as`** `V` is also just fine, and exactly equivalent to **`import`** `P.M` **`as`** `V`. You can also use *relative* paths: that is, module `M` in package `P` can import its "sibling" module `X` (also in package `P`) with **`from . import`** `X`.

> **Sharing Objects Among Modules in a Package**
>
> The simplest, cleanest way to share objects (e.g., functions or constants) among modules in a package `P` is to group the shared objects in a module conventionally named *common.py*. That way, you can use **`from . import`** `common` in every module in the package that needs to access some of the common objects, and then refer to the objects as `common.f`, `common.K`, and so on.

Special Attributes of Package Objects

A package `P`'s `__file__` attribute is the string that is the path of `P`'s module body—that is, the path of the file *P/__init__.py*. `P`'s `__package__` attribute is the name of `P`'s package.

A package `P`'s module body—that is, the Python source that is in the file *P/__init__.py*—can optionally set a global variable named `__all__` (just like any other module can) to control what happens if some other Python code executes the statement **`from`** `P` **`import`** `*`. In particular, if `__all__` is not set, **`from`** `P` **`import`** `*` does not import `P`'s modules, but only names that are set in `P`'s module body and lack a leading `_`. In any case, this is *not* recommended usage.

A package `P`'s `__path__` attribute is the list of strings that are the paths to the directories from which `P`'s modules and subpackages are loaded. Initially, Python sets `__path__` to a list with a single element: the path of the directory containing the file *__init__.py* that is the module body of the package. Your code can modify this list to affect future searches for modules and subpackages of this package. This advanced technique is rarely necessary, but can be useful when you want to place a package's modules in multiple directories (a namespace package is, however, the usual way to accomplish this goal).

Absolute Versus Relative Imports

As mentioned previously, an **`import`** statement normally expects to find its target somewhere on `sys.path`—a behavior known as an *absolute* import. Alternatively, you can explicitly use a *relative* import, meaning an import of an object from within the current package. Using relative imports can make it easier for you to refactor or restructure the subpackages within your package. Relative imports use module or package names beginning with one or more dots, and are only available within the **from** statement. **from . import** *X* looks for the module or object named *X* in the current package; **from .***X* **import** *y* looks in module or subpackage *X* within the current package for the module or object named *y*. If your package has subpackages, their code can access higher-up objects in the package by using multiple dots at the start of the module or subpackage name you place between **from** and **import**. Each additional dot ascends the directory hierarchy one level. Getting too fancy with this feature can easily damage your code's clarity, so use it with care, and only when necessary.

Distribution Utilities (distutils) and setuptools

Python modules, extensions, and applications can be packaged and distributed in several forms:

Compressed archive files
: Generally *.zip*, *.tar.gz* (aka *.tgz*), *.tar.bz2*, or *.tar.xz* files—all these forms are portable, and many other forms of compressed archives of trees of files and directories exist

Self-unpacking or self-installing executables
: Normally *.exe* for Windows

Self-contained, ready-to-run executables that require no installation
: For example, *.exe* for Windows, ZIP archives with a short script prefix on Unix, *.app* for the Mac, and so on

Platform-specific installers
: For example, *.rpm* and *.srpm* on many Linux distributions, *.deb* on Debian GNU/Linux and Ubuntu, *.pkg* on macOS

Python wheels
: Popular third-party extensions, covered in the following note

> **Python Wheels**
> A Python *wheel* is an archive file including structured metadata as well as Python code. Wheels offer an excellent way to package and distribute your Python packages, and `setuptools` (with the `wheel` extension, easily installed with **`pip install wheel`**) works seamlessly with them. Read all about them at PythonWheels.com and in Chapter 24 (available online).

When you distribute a package as a self-installing executable or platform-specific installer, a user simply runs the installer. How to run such a program depends on the platform, but it doesn't matter which language the program was written in. We cover building self-contained, runnable executables for various platforms in Chapter 24.

When you distribute a package as an archive file or as an executable that unpacks but does not install itself, it *does* matter that the package was coded in Python. In this case, the user must first unpack the archive file into some appropriate directory, say *C:\Temp\MyPack* on a Windows machine or *~/MyPack* on a Unix-like machine. Among the extracted files there should be a script, conventionally named *setup.py*, that uses the Python facility known as the *distribution utilities* (the now deprecated, but still functioning, standard library package `distutils`[2]) or, better, the more popular, modern, and powerful third-party package setuptools. The distributed package is then almost as easy to install as a self-installing executable; the user simply opens a command prompt window, changes to the directory into which the archive is unpacked, then runs, for example:

```
C:\Temp\MyPack> python setup.py install
```

(Another, often preferable, option is to use `pip`; we'll describe that momentarily.) The *setup.py* script run with this **`install`** command installs the package as a part of the user's Python installation, according to the options specified by the package's author in the setup script. Of course, the user needs appropriate permissions to write into the directories of the Python installation, so permission-raising commands such as `sudo` may also be needed; or, better yet, you can install into a *virtual environment*, as described in the next section. `distutils` and `setuptools`, by default, print some information when the user runs *setup.py*. Including the option **`--quiet`** right before the **`install`** command hides most details (the user still sees error messages, if any). The following command gives detailed help on `distutils` or `setuptools`, depending on which toolset the package author used in their *setup.py*:

```
C:\Temp\MyPack> python setup.py --help
```

An alternative to this process, and the preferred way to install packages nowadays, is to use the excellent installer `pip` that comes with Python. `pip`—a recursive acronym for "`pip` installs packages"—is copiously documented online, yet very simple to use in most cases. **`pip install`** ***`package`*** finds the online version of *`package`* (usually in the huge PyPI repository, hosting more than 400,000 packages at the time of this writing), downloads it, and installs it for you (in a virtual environment, if one is active; see the next section for details). This books' authors have been using that simple, powerful approach for well over 90% of their installs for quite a while now.

Even if you have downloaded the package locally (say to */tmp/mypack*), for whatever reason (maybe it's not on PyPI, or you're trying out an experimental version that is not yet there), `pip` can still install it for you: just run **`pip install --no-index --find-links=/tmp/mypack`** and `pip` does the rest.

2 `distutils` is scheduled for deletion in Python 3.12.

Python Environments

A typical Python programmer works on several projects concurrently, each with its own list of dependencies (typically, third-party libraries and data files). When the dependencies for all projects are installed into the same Python interpreter, it is very difficult to determine which projects use which dependencies, and impossible to handle projects with conflicting versions of certain dependencies.

Early Python interpreters were built on the assumption that each computer system would have "a Python interpreter" installed on it, to be used to run any Python program on that system. Operating system distributions soon started to include Python in their base installations, but, because Python has always been under active development, users often complained that they would like to use a more up-to-date version of the language than the one their operating system provided.

Techniques arose to let multiple versions of the language be installed on a system, but installation of third-party software remained nonstandard and intrusive. This problem was eased by the introduction of the *site-packages* directory as the repository for modules added to a Python installation, but it was still not possible to maintain multiple projects with conflicting requirements using the same interpreter.

Programmers accustomed to command-line operations are familiar with the concept of a *shell environment*. A shell program running in a process has a current directory, variables that you can set with shell commands (very similar to a Python namespace), and various other pieces of process-specific state data. Python programs have access to the shell environment through `os.environ`.

Various aspects of the shell environment affect Python's operation, as mentioned in "Environment Variables" on page 22. For example, the `PATH` environment variable determines which program, exactly, executes in response to **`python`** and other commands. You can think of those aspects of your shell environment that affect Python's operation as your *Python environment*. By modifying it you can determine which Python interpreter runs in response to the **`python`** command, which packages and modules are available under certain names, and so on.

Leave the System's Python to the System

We recommend taking control of your Python environment. In particular, do not build applications on top of a system-distributed Python. Instead, install another Python distribution independently, and adjust your shell environment so that the **`python`** command runs your locally installed Python rather than the system's Python.

Enter the Virtual Environment

The introduction of the `pip` utility created a simple way to install (and, for the first time, to uninstall) packages and modules in a Python environment. Modifying the system Python's *site-packages* still requires administrative privileges, and hence so does `pip` (although it can optionally install somewhere other than *site-packages*). Modules installed in the central *site-packages* are visible to all programs.

The missing piece is the ability to make controlled changes to the Python environment, to direct the use of a specific interpreter and a specific set of Python libraries. That functionality is just what *virtual environments* (*virtualenvs*) give you. Creating a virtualenv based on a specific Python interpreter copies or links to components from that interpreter's installation. Critically, though, each one has its own *site-packages* directory, into which you can install the Python resources of your choice.

Creating a virtualenv is *much* simpler than installing Python, and requires far less system resources (a typical newly created virtualenv takes up less than 20 MB). You can easily create and activate virtualenvs on demand, and deactivate and destroy them just as easily. You can activate and deactivate a virtualenv as many times as you like during its lifetime, and if necessary use `pip` to update the installed resources. When you are done with it, removing its directory tree reclaims all storage occupied by the virtualenv. A virtualenv's lifetime can span minutes or months.

What Is a Virtual Environment?

A virtualenv is essentially a self-contained subset of your Python environment that you can switch in or out on demand. For a Python 3.*x* interpreter it includes, among other things, a *bin* directory containing a Python 3.*x* interpreter, and a *lib/python3.x/site-packages* directory containing preinstalled versions of `easy-install`, `pip`, `pkg_resources`, and `setuptools`. Maintaining separate copies of these important distribution-related resources lets you update them as necessary rather than forcing you to rely on the base Python distribution.

A virtualenv has its own copies of (on Windows) or symbolic links to (on other platforms) Python distribution files. It adjusts the values of `sys.prefix` and `sys.exec_prefix`, from which the interpreter and various installation utilities determine the locations of some libraries. This means that `pip` can install dependencies in isolation from other environments, in the virtualenv's *site-packages* directory. In effect, the virtualenv redefines which interpreter runs when you run the **`python`** command and which libraries are available to it, but leaves most aspects of your Python environment (such as the `PYTHONPATH` and `PYTHONHOME` variables) alone. Since its changes affect your shell environment, they also affect any subshells in which you run commands.

With separate virtualenvs you can, for example, test two different versions of the same library with a project, or test your project with multiple versions of Python. You can also add dependencies to your Python projects without needing any special privileges, since you normally create your virtualenvs somewhere you have write permission.

The modern way to deal with virtualenvs is with the `venv` module of the standard library: just run **`python -m venv`** *`envpath`*.

Creating and Deleting Virtual Environments

The command **python -m venv** *envpath* creates a virtual environment (in the *envpath* directory, which it also creates if necessary) based on the Python interpreter used to run the command. You can give multiple directory arguments to create, with a single command, several virtual environments (running the same Python interpreter); you can then install different sets of dependencies in each virtualenv. venv can take a number of options, as shown in Table 7-1.

Table 7-1. venv options

Option	Purpose
--clear	Removes any existing directory content before installing the virtual environment
--copies	Installs files by copying on the Unix-like platforms where using symbolic links is the default
--h or **--help**	Prints out a command-line summary and a list of available options
--symlinks	Installs files by using symbolic links on platforms where copying is the system default
--system-site-packages	Adds the standard system *site-packages* directory to the environment's search path, making modules already installed in the base Python available inside the environment
--upgrade	Installs the running Python in the virtual environment, replacing whichever version had originally created the environment
--without-pip	Inhibits the usual behavior of calling ensurepip to bootstrap the pip installer utility into the environment

Know Which Python You're Running

When you enter the command **python** at the command line, your shell has rules (which differ among Windows, Linux, and macOS) that determine which program you run. If you are clear on those rules, you always know which interpreter you are using.

Using **python -m venv** *directory_path* to create a virtual environment guarantees that it's based on the same Python version as the interpreter used to create it. Similarly, using **python -m pip** *package_name* will install the package for the interpreter associated with the **python** command. Activating a virtual environment changes the association with the **python** command: this is the simplest way to ensure packages are installed into the virtual environment.

The following Unix terminal session shows the creation of a virtualenv and the structure of the created directory tree. The listing of the *bin* subdirectory shows that this particular user, by default, uses an interpreter installed in */usr/local/bin*.[3]

```
$ python3 -m venv /tmp/tempenv
$ tree -dL 4 /tmp/tempenv
/tmp/tempenv
|--- bin
|--- include
|___ lib
     |___ python3.5
          |___ site-packages
               |--- __pycache__
               |--- pip
               |--- pip-8.1.1.dist-info
               |--- pkg_resources
               |--- setuptools
               |___ setuptools-20.10.1.dist-info

11 directories
$ ls -l /tmp/tempenv/bin/
total 80
-rw-r--r-- 1 sh wheel 2134 Oct 24 15:26 activate
-rw-r--r-- 1 sh wheel 1250 Oct 24 15:26 activate.csh
-rw-r--r-- 1 sh wheel 2388 Oct 24 15:26 activate.fish
-rwxr-xr-x 1 sh wheel  249 Oct 24 15:26 easy_install
-rwxr-xr-x 1 sh wheel  249 Oct 24 15:26 easy_install-3.5
-rwxr-xr-x 1 sh wheel  221 Oct 24 15:26 pip
-rwxr-xr-x 1 sh wheel  221 Oct 24 15:26 pip3
-rwxr-xr-x 1 sh wheel  221 Oct 24 15:26 pip3.5
lrwxr-xr-x 1 sh wheel    7 Oct 24 15:26 python->python3
lrwxr-xr-x 1 sh wheel   22 Oct 24 15:26 python3->/usr/local/bin/python3
```

Deleting a virtualenv is as simple as removing the directory in which it resides (and all subdirectories and files in the tree: **`rm -rf`** *`envpath`* in Unix-like systems). Ease of removal is a helpful aspect of using virtualenvs.

The `venv` module includes features to help the programmed creation of tailored environments (e.g., by preinstalling certain modules in the environment or performing other post-creation steps). It is comprehensively documented online; we do not cover the API further in this book.

3 When running these commands on reduced-footprint Linux distributions, you may need to separately install `venv` or other supporting packages first.

Working with Virtual Environments

To use a virtualenv, you *activate* it from your normal shell environment. Only one virtualenv can be active at a time—activations don't "stack" like function calls. Activation tells your Python environment to use the virtualenv's Python interpreter and *site-packages* (along with the interpreter's full standard library). When you want to stop using those dependencies, deactivate the virtualenv, and your standard Python environment is once again available. The virtualenv directory tree continues to exist until deleted, so you can activate and deactivate it at will.

Activating a virtualenv in Unix-based environments requires using the **`source`** shell command so that the commands in the activation script make changes to the current shell environment. Simply running the script would mean its commands were executed in a subshell, and the changes would be lost when the subshell terminated. For bash, `zsh`, and similar shells, you activate an environment located at path *`envpath`* with the command:

```
$ source envpath/bin/activate
```

or:

```
$ . envpath/bin/activate
```

Users of other shells are supported by the scripts *activate.csh* and *activate.fish*, located in the same directory. On Windows systems, use *activate.bat* (or, if using Powershell, *Activate.ps1*):

```
C:\> envpath/Scripts/activate.bat
```

Activation does many things. Most importantly, it:

- Adds the virtualenv's *bin* directory at the beginning of the shell's `PATH` environment variable, so its commands get run in preference to anything of the same name already on the `PATH`
- Defines a `deactivate` command to remove all effects of activation and return the Python environment to its former state
- Modifies the shell prompt to include the virtualenv's name at the start
- Defines a `VIRTUAL_ENV` environment variable as the path to the virtualenv's root directory (scripts can use this to introspect the virtualenv)

As a result of these actions, once a virtualenv is activated, the **`python`** command runs the interpreter associated with that virtualenv. The interpreter sees the libraries (modules and packages) installed in that environment, and `pip`—now the one from the virtualenv, since installing the module also installed the command in the virtualenv's *bin* directory—by default installs new packages and modules in the environment's *site-packages* directory.

Those new to virtualenvs should understand that a virtualenv is not tied to any project directory. It's perfectly possible to work on several projects, each with its own source tree, using the same virtualenv. Activate it, then move around your filesystem as necessary to accomplish your programming tasks, with the same libraries available (because the virtualenv determines the Python environment).

When you want to disable the virtualenv and stop using that set of resources, simply issue the command **`deactivate`**. This undoes the changes made on activation, removing the virtualenv's *bin* directory from your `PATH`, so the **`python`** command once again runs your usual interpreter. As long as you don't delete it, the virtualenv remains available for future use: just repeat the command to activate it.

Do Not Use py –3.x in a Virtualenv on Windows

The Windows py launcher provides mixed support for virtualenvs. It makes it very easy to define a virtualenv using a specific Python version, using a command like the following:

```
C:\> py -3.7 -m venv C:\path\to\new_virtualenv
```

This creates a new virtualenv, running the installed Python 3.7.

Once activated, you can run the Python interpreter in the virtualenv using either the **`python`** command or the bare **`py`** command with no version specified. However, if you specify the **`py`** command using a version option, even if it is the same version used to construct the virtualenv, you will *not* run the *virtualenv* Python. Instead, you will run the corresponding *system-installed* version of Python.

Managing Dependency Requirements

Since virtualenvs were designed to complement installation with `pip`, it should come as no surprise that `pip` is the preferred way to maintain dependencies in a virtualenv. Because `pip` is already extensively documented, we mention only enough here to demonstrate its advantages in virtual environments. Having created a virtualenv, activated it, and installed dependencies, you can use the **`pip freeze`** command to learn the exact versions of those dependencies:

```
(tempenv) $ pip freeze
appnope==0.1.0
decorator==4.0.10
ipython==5.1.0
ipython-genutils==0.1.0
pexpect==4.2.1
pickleshare==0.7.4
prompt-toolkit==1.0.8
ptyprocess==0.5.1
Pygments==2.1.3
requests==2.11.1
simplegeneric==0.8.1
six==1.10.0
traitlets==4.3.1
wcwidth==0.1.7
```

If you redirect the output of this command to a file called *filename*, you can re-create the same set of dependencies in a different virtualenv with the command **pip install -r** ***filename***.

When distributing code for use by others, Python developers conventionally include a *requirements.txt* file listing the necessary dependencies. `pip` installs any indicated dependencies along with the packages you request when you install software from PyPI. While you're developing software it's also convenient to have a requirements file, as you can use it to add the necessary dependencies to the active virtualenv (unless they are already installed) with a simple **pip install -r requirements.txt**.

To maintain the same set of dependencies in several virtualenvs, use the same requirements file to add dependencies to each one. This is a convenient way to develop projects to run on multiple Python versions: create virtualenvs based on each of your required versions, then install from the same requirements file in each. While the preceding example uses exactly versioned dependency specifications as produced by **pip freeze**, in practice you can specify dependencies and version requirements in quite complex ways; see the documentation for details.

Other Environment Management Solutions

Python virtual environments are focused on providing an isolated Python interpreter, into which you can install dependencies for one or more Python applications. The `virtualenv` package was the original way to create and manage virtualenvs. It has extensive facilities, including the ability to create environments from any available Python interpreter. Now maintained by the Python Packaging Authority team, a subset of its functionality has been extracted as the standard library `venv` module covered earlier, but `virtualenv` is worth learning about if you need more control.

The `pipenv` package is another dependency manager for Python environments. It maintains virtual environments whose contents are recorded in a file named *Pipfile*. Much in the manner of similar JavaScript tools, it provides deterministic environments through the use of a *Pipfile.lock* file, allowing the exact same dependencies to be deployed as in the original installation.

Modules and Packages

`conda`, mentioned in "Anaconda and Miniconda" on page 8, has a rather broader scope and can provide package, environment, and dependency management for any language. `conda` is written in Python, and installs its own Python interpreter in the base environment. Whereas a standard Python virtualenv normally uses the Python interpreter with which it was created; in `conda`, Python itself (when it is included in the environment) is simply another dependency. This makes it practical to update the version of Python used in the environment, if necessary. You can also, if you wish, use `pip` to install packages in a Python-based `conda` environment. `conda` can dump an environment's contents as a YAML file, and you can use the file to replicate the environment elsewhere.

Because of its additional flexibility, coupled with comprehensive open source support led by its originator, Anaconda, Inc. (formerly Continuum), `conda` is widely used in academic environments, particularly in data science and engineering, artificial intelligence, and financial analytics. It installs software from what it calls *channels*. The default channel maintained by Anaconda contains a wide range of packages, and third parties maintain specialized channels (such as the *bioconda* channel for bioinformatics software). There is also a community-based *conda-forge* channel, open to anyone who wants to join up and add software. Signing up for an account on Anaconda.org lets you create your own channel and distribute software through the *conda-forge* channel.

Best Practices with Virtualenvs

There is remarkably little advice on how best to manage your work with virtualenvs, though there are several sound tutorials: any good search engine will give you access to the most current ones. We can, however, offer a modest amount of advice that we hope will help you to get the most out of virtual environments.

When you are working with the same dependencies in multiple Python versions, it is useful to indicate the version in the environment name and use a common prefix. So, for the project *mutex* you might maintain environments called *mutex_39* and *mutex_310* for development under two different versions of Python. When it's obvious which Python is involved (remember, you see the environment name in your shell prompt), there's less risk of testing with the wrong version. You can maintain dependencies using common requirements to control resource installation in both.

Keep the requirements file(s) under source control, not the whole environment. Given the requirements file it's easy to re-create a virtualenv, which depends only on the Python release and the requirements. You distribute your project, and let your users decide which version(s) of Python to run it on and create the appropriate virtual environment(s).

Keep your virtualenvs outside your project directories. This avoids the need to explicitly force source code control systems to ignore them. It really doesn't matter where else you store them.

Your Python environment is independent of your projects' locations in the filesystem. You can activate a virtual environment and then switch branches and move around a change-controlled source tree to use it wherever is convenient.

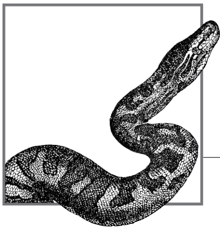
To investigate a new module or package, create and activate a new virtualenv and then **`pip install`** the resources that interest you. You can play with this new environment to your heart's content, confident in the knowledge that you won't be installing unwanted dependencies into other projects.

You may find that experiments in a virtualenv require installation of resources that aren't currently project requirements. Rather than "pollute" your development environment, fork it: create a new virtualenv from the same requirements plus the testing functionality. Later, to make these changes permanent, use change control to merge your source and requirements changes back in from the forked branch.

If you are so inclined, you can create virtual environments based on debug builds of Python, giving you access to a wealth of information about the performance of your Python code (and, of course, of the interpreter itself).

Developing a virtual environment also requires change control, and the ease of virtualenv creation helps here too. Suppose that you recently released version 4.3 of a module, and you want to test your code with new versions of two of its dependencies. You *could*, with sufficient skill, persuade `pip` to replace the existing copies of dependencies in your existing virtualenv. It's much easier, though, to branch your project using source control tools, update the requirements, and create an entirely new virtual environment based on the updated requirements. The original virtualenv remains intact, and you can switch between virtualenvs to investigate specific aspects of any migration issues that might arise. Once you have adjusted your code so that all tests pass with the updated dependencies, you can check in your code *and* requirement changes and merge into version 4.4 to complete the update, advising your colleagues that your code is now ready for the updated versions of the dependencies.

Virtual environments won't solve all of a Python programmer's problems: tools can always be made more sophisticated, or more general. But, by golly, virtualenvs work, and we should take all the advantage of them that we can.



8
Core Built-ins and Standard Library Modules

The term *built-in* has more than one meaning in Python. In many contexts, *built-in* means an object directly accessible to Python code without an **import** statement. The section "Python built-ins" on page 224 shows Python's mechanism to allow this direct access. Built-in types in Python include numbers, sequences, dictionaries, sets, functions (all covered in Chapter 3), classes (covered in "Python Classes" on page 115), standard exception classes (covered in "Exception Objects" on page 205), and modules (covered in "Module Objects" on page 222). "The io Module" on page 322 covers the `file` type, and "Internal Types" on page 434 some other built-in types intrinsic to Python's internal operation. This chapter provides additional coverage of built-in core types in the opening section and covers built-in functions available in the module `builtins` in "Built-in Functions" on page 251.

Some modules are called "built-in" because they're in the Python standard library (though it takes an **import** statement to use them), as opposed to add-on modules, also known as Python *extensions*.

This chapter covers several built-in core modules: namely, the standard library modules `sys`, `copy`, `collections`, `functools`, `heapq`, `argparse`, and `itertools`. You'll find a discussion of each module *x* in the respective section "The *x* Module."

Chapter 9 covers some string-related built-in core modules (`string`, `codecs`, and `unicodedata`) with the same section-name convention. Chapter 10 covers `re` in "Regular Expressions and the re Module" on page 305.

Built-in Types

Table 8-1 provides a brief overview of Python's core built-in types. More details about many of these types, and about operations on their instances, are found throughout Chapter 3. In this section, by "any number" we mean, specifically, "any noncomplex number." Also, many built-ins accept at least some of their parameters in a positional-only way; we use the **3.8+** positional-only marker `/`, covered in "Positional-only marker" on page 96, to indicate this.

Table 8-1. Python's core built-in types

`bool`	`bool(x=False, /)` Returns **`False`** when *x* evaluates as falsy; returns **`True`** when *x* evaluates as truthy (see "Boolean Values" on page 51). `bool` extends `int`: the built-in names **`False`** and **`True`** refer to the only two instances of `bool`. These instances are also `int`s equal to `0` and `1`, respectively, but `str(True)` is `'True'` and `str(False)` is `'False'`.
`bytearray`	`bytearray(x=b'', /[, codec[, errors]])` Returns a mutable sequence of bytes (`int`s with values from `0` to `255`), supporting the usual methods of mutable sequences, plus the methods of `str`. When *x* is a `str`, you must also pass `codec` and may pass `errors`; the result is just like calling `bytearray(x.encode(codec, errors))`. When *x* is an `int`, it must be `>=0`: the resulting instance has a length of *x*, and each item is initialized to `0`. When *x* conforms to the buffer protocol, the read-only buffer of bytes from *x* initializes the instance. Otherwise, *x* must be an iterable yielding `int`s `>=0` and `<256`; e.g., `bytearray([1,2,3,4]) == bytearray(b'\x01\x02\x03\x04')`.
`bytes`	`bytes(x=b'', /[, codec[, errors]])` Returns an immutable sequence of bytes, with the same nonmutating methods and the same initialization behavior as `bytearray`.
`complex`	`complex(real=0, imag=0)` Converts any number, or a suitable string, to a complex number. `imag` may be present only when `real` is a number, and in that case `imag` is also a number: the imaginary part of the resulting complex number. See also "Complex numbers" on page 42.

`dict`	`dict(x={}, /)`
	Returns a new dictionary with the same items as *x*. (We cover dictionaries in "Dictionaries" on page 49.) When *x* is a `dict`, `dict(x)` returns a shallow copy of *x*, like `x.copy()`. Alternatively, *x* can be an iterable whose items are pairs (iterables with two items each). In this case, `dict(x)` returns a dictionary whose keys are the first items of each pair in *x*, and whose values are the corresponding second items. When a key appears more than once in *x*, Python uses the value corresponding to the last occurrence of the key. In other words, when *x* is any iterable yielding pairs, *c* = `dict(x)` is exactly equivalent to:
	`c = {}`
	`for key, value in x:`
	`    c[key] = value`
	You can also call `dict` with named arguments, in addition to, or instead of, positional argument *x*. Each named argument becomes an item in the dictionary, with the name as the key: each such extra item might "overwrite" an item from *x*.

`float`	`float(x=0.0, /)` Converts any number, or a suitable string, to a floating-point number. See "Floating-point numbers" on page 41.

`frozenset`	`frozenset(seq=(), /)` Returns a new frozen (i.e., immutable) set object with the same items as iterable *seq*. When *seq* is a frozenset, `frozenset(seq)` returns *seq* itself, just like `seq.copy()` does. See "Set Operations" on page 69.
`int`	`int(x=0, /, base=10)` Converts any number, or a suitable string, to an `int`. When *x* is a number, `int` truncates toward `0`, "dropping" any fractional part. `base` may be present only when *x* is a string: then, `base` is the conversion base, between `2` and `36`, with `10` as the default. You can explicitly pass `base` as `0`: the base is then `2`, `8`, `10`, or `16`, depending on the form of string *x*, just like for integer literals, as covered in "Integer numbers" on page 41.
`list`	`list(seq=(), /)` Returns a new list object with the same items as iterable *seq*, in the same order. When *seq* is a list, `list(seq)` returns a shallow copy of *seq*, like `seq[:]`. See "Lists" on page 47.
`memoryview`	`memoryview(x, /)` Returns an object *m* "viewing" exactly the same underlying memory as *x*, which must be an object supporting the buffer protocol (for example, an instance of `bytes`, `bytearray`, or `array.array`), with items of `m.itemsize` bytes each. In the normal case in which *m* is "one-dimensional" (we don't cover the complicated case of "multidimensional" `memoryview` instances in this book), `len(m)` is the number of items. You can index *m* (returning `int`) or slice it (returning an instance of `memoryview` "viewing" the appropriate subset of the same underlying memory). *m* is mutable when *x* is (but you can't change *m*'s size, so, when you assign to a slice, it must be from an iterable of the same length as the slice). *m* is a sequence, thus iterable, and is hashable when *x* is hashable and when `m.itemsize` is one byte. *m* supplies several read-only attributes and methods; see the online docs for details. Two particularly useful methods are `m.tobytes` (returns *m*'s data as an instance of `bytes`) and `m.tolist` (returns *m*'s data as a list of `int`s).

`object`	`object()`
	Returns a new instance of `object`, the most fundamental type in Python. Instances of type `object` have no functionality: the only use of such instances is as "sentinels"—i.e., objects not equal to any distinct object. For instance, when a function takes an optional argument where **None** is a legitimate value, you can use a sentinel for the argument's default value to indicate that the argument was omitted:
	`MISSING = object()`
	`def check_for_none(obj=MISSING):`
	`    if obj is MISSING:`
	`        return -1`
	`    return 0 if obj is None else 1`

`set`	`set(seq=(), /)` Returns a new mutable set object with the same items as iterable *seq*. When *seq* is a set, `set(seq)` returns a shallow copy of *seq*, like `seq.copy()`. See "Sets" on page 48.

Core Built-ins and Modules

`slice`	`slice([start, ]stop[, step], /)` Returns a slice object with the read-only attributes `start`, `stop`, and `step` bound to the respective argument values, each defaulting to **None** when missing. For positive indices, such a slice signifies the same indices as `range(start, stop, step)`. Slicing syntax, *`obj`*`[start:stop:step]`, passes a slice object as the argument to the `__getitem__`, `__setitem__`, or `__delitem__` method of object *`obj`*. It is up to *`obj`*'s class to interpret the slices that its methods receive. See also "Container slicing" on page 149.
`str`	`str(`*`obj`*`='', /)` Returns a concise, readable string representation of *`obj`*. If *`obj`* is a string, `str` returns *`obj`*. See also `repr` in Table 8-2 and `__str__` in Table 4-1.
`super`	`super(), super(`*`cls`*`, `*`obj`*`, /)` Returns a superobject of object *`obj`* (which must be an instance of class *`cls`* or of any subclass of *`cls`*), suitable for calling superclass methods. Instantiate this built-in type only within a method's code. The `super(`*`cls`*`, `*`obj`*`)` syntax is a legacy form from Python 2 that has been retained for compatibility. In new code, you usually call `super()` without arguments, within a method, and Python determines the *`cls`* and *`obj`* by introspection (as `type(self)` and `self`, respectively). See "Cooperative superclass method calling" on page 132.
`tuple`	`tuple(`*`seq`*`=(), /)` Returns a tuple with the same items as iterable *`seq`*, in order. When *`seq`* is a tuple, `tuple` returns *`seq`* itself, like *`seq`*`[:]`. See "Tuples" on page 47.
`type`	`type(`*`obj`*`, /)` Returns the type object that is the type of *`obj`* (i.e., the most-derived, aka *leafmost*, type of which *`obj`* is an instance). `type(`*`x`*`)` is the same as *`x`*`.__class__` for any *x*. Avoid checking equality or identity of types (see the following warning for details). This function is commonly used for debugging; for example, when value *x* does not behave as expected, inserting `print(type(`*`x`*`), `*`x`*`)`. It can also be used to dynamically create classes at runtime, as described in Chapter 4.

Type Equality Checking: Avoid It!

Use `isinstance` (covered in Table 8-2), *not* equality comparison of types, to check whether an instance belongs to a particular class in order to support inheritance properly.[1] Using `type(`*`x`*`)` to check for equality or identity to some other type object is known as *type equality checking*. Type equality checking is inappropriate in production Python code, as it interferes with polymorphism. Typically, you just try to use *`x`* *as if* it were of the type you expect, handling any problems with a **`try`**`/`**`except`** statement, as discussed in "Error-Checking Strategies" on page 214; this is known as *duck typing* (one of this book's authors is often credited with an early use of this colorful phrase).

1 I.e., according to the Liskov substitution principle, a core notion of object-oriented programming.

When you just *have* to type-check, usually for debugging purposes, use `isinstance` instead. In a broader sense, `isinstance(x, atype)` is also a form of type checking, but it is a lesser evil than `type(x) is atype`. `isinstance` accepts an `x` that is an instance of any subclass of `atype`, or an object that implements protocol `atype`, not just a *direct* instance of `atype` itself. In particular, `isinstance` is fine when you're checking for an abstract base class (see "Abstract Base Classes" on page 150) or protocol (see "Protocols" on page 179); this newer idiom is also sometimes known as *goose typing* (again, this phrase is credited to one of this book's authors).

Built-in Functions

Table 8-2 covers Python functions (and some types that, in practice, are only used *as if* they were functions) in the module `builtins`, in alphabetical order. Built-ins' names are *not* keywords. This means you *can* bind, in local or global scope, an identifier that's a built-in name, although we recommend avoiding it (see the following warning!). Names bound in local or global scope override names bound in built-in scope, so local and global names *hide* built-in ones. You can also rebind names in built-in scope, as covered in "Python built-ins" on page 224.

Don't Hide Built-ins

Avoid accidentally hiding built-ins: your code might need them later. It's often tempting to use natural names such as `input`, `list`, or `filter` for your own variables, but *don't do it*: these are names of built-in Python types or functions, and reusing them for your own purposes makes those built-in types and functions inaccessible. Unless you get into the habit of *never* hiding built-ins' names with your own, sooner or later you'll get mysterious bugs in your code caused by just such hiding occurring accidentally.

Many built-in functions cannot be called with named arguments, only with positional ones. In Table 8-2, we mention cases in which this limitation does not hold; when it does, we also use the **3.8+** positional-only marker `/`, covered in "Positional-only marker" on page 96.

Table 8-2. Python's core built-in functions

`__import__`	`__import__(module_name[, globals[, locals[, fromlist]]], /)` Deprecated in modern Python; use `importlib.import_module`, covered in "Module Loading" on page 227.
`abs`	`abs(x, /)` Returns the absolute value of number *x*. When *x* is complex, `abs` returns the square root of `x.imag ** 2 + x.real ** 2` (also known as the magnitude of the complex number). Otherwise, `abs` returns `-x` when `x < 0`, or *x* when `x >= 0`. See also `__abs__`, `__invert__`, `__neg__`, and `__pos__` in Table 4-4.

`all`	`all(`*`seq`*`, /)`
	`seq` is an iterable. `all` returns **`False`** when any item of *`seq`* is falsy; otherwise, `all` returns **`True`**. Like the operators **and** and **or**, covered in "Short-Circuiting Operators" on page 58, `all` stops evaluating and returns a result as soon as it knows the answer; in the case of `all`, this means it stops as soon as a falsy item is reached, but proceeds throughout *`seq`* if all of *`seq`*'s items are truthy. Here is a typical toy example of the use of `all`:
	`if all(x>0 for x in the_numbers):`
	`    print('all of the numbers are positive')`
	`else:`
	`    print('some of the numbers are not positive')`
	When *`seq`* is empty, `all` returns **`True`**.

`any`	`any(`*`seq`*`, /)`
	`seq` is an iterable. `any` returns **`True`** if any item of *`seq`* is truthy; otherwise, `any` returns **`False`**. Like the operators **and** and **or**, covered in "Short-Circuiting Operators" on page 58, `any` stops evaluating and returns a result as soon as it knows the answer; in the case of `any`, this means it stops as soon as a truthy item is reached, but proceeds throughout *`seq`* if all of *`seq`*'s items are falsy. Here is a typical toy example of the use of `any`:
	`if any(x<0 for x in the_numbers):`
	`    print('some of the numbers are negative')`
	`else:`
	`    print('none of the numbers are negative')`
	When *`seq`* is empty, `any` returns **`False`**.

`ascii`	`ascii(`*`x`*`, /)` Like `repr`, but escapes non-ASCII characters in the string it returns; the result is usually similar to that of `repr`.
`bin`	`bin(`*`x`*`, /)` Returns a binary string representation of integer *x*. E.g., `bin(23)=='0b10111'`.
`breakpoint`	`breakpoint()` Invokes the `pdb` Python debugger. Set `sys.breakpointhook` to a callable function if you want `breakpoint` to invoke an alternate debugger.
`callable`	`callable(`*`obj`*`, /)` Returns **`True`** when *`obj`* can be called; otherwise, returns **`False`**. An object can be called if it is a function, method, class, or type, or an instance of a class with a `__call__` method. See also `__call__` in Table 4-1.
`chr`	`chr(`*`code`*`, /)` Returns a string of length `1`, a single character corresponding to the integer *`code`* in Unicode. See also `ord` later in this table.

`compile`	`compile(`*`source`*`, `*`filename`*`, `*`mode`*`)` Compiles a string and returns a code object usable by `exec` or `eval`. `compile` raises `SyntaxError` when *`source`* is not syntactically valid Python. When *`source`* is a multiline compound statement, the last character must be `'\n'`. *`mode`* must be `'eval'` when *`source`* is an expression and the result is meant for `eval`; otherwise, *`mode`* must be `'exec'` (for a single or multiple-statement string) or `'single'` (for a string containing a single statement) when the string is meant for `exec`. *`filename`* must be a string, used only in error messages (if an error occurs). See also `eval` later in this table, and "compile and Code Objects" on page 432. (`compile` also takes the optional arguments `flags`, `dont_inherit`, `optimize`, and **3.11+** `_feature_version`, though these are rarely used; see the online documentation for more information on these arguments.)
`delattr`	`delattr(`*`obj`*`, `*`name`*`, /)` Removes the attribute *`name`* from *`obj`*. `delattr(`*`obj`*`, '`*`ident`*`')` is like `del` *`obj`*`.`*`ident`*. If *`obj`* has an attribute named *`name`* just because its class has it (as is normally the case, for example, for *methods* of *`obj`*), you cannot delete that attribute from *`obj`* itself. You may be able to delete that attribute from the *class*, if the metaclass lets you. If you can delete the class attribute, *`obj`* ceases to have the attribute, and so does every other instance of that class.
`dir`	`dir([`*`obj`*`, ]/)` Called without arguments, `dir` returns a sorted list of all variable names that are bound in the current scope. `dir(`*`obj`*`)` returns a sorted list of names of attributes of *`obj`*, including ones coming from *`obj`*'s type or by inheritance. See also `vars` later in this table.
`divmod`	`divmod(`*`dividend`*`, `*`divisor`*`, /)` Divides two numbers and returns a pair whose items are the quotient and remainder. See also `__divmod__` in Table 4-4.

`enumerate`	`enumerate(iterable, start=0)`
	Returns a new iterator whose items are pairs. For each such pair, the second item is the corresponding item in `iterable`, while the first item is an integer: `start, start+1, start+2....` For example, the following snippet loops on a list `L` of integers, changing `L` in place by halving every even value:
	`for i, num in enumerate(L):`
	`    if num % 2 == 0:`
	`        L[i] = num // 2`
	`enumerate` is one of the few built-ins callable with named arguments.

`eval`	`eval(`*`expr`*`[, `*`globals`*`[, `*`locals`*`]], /)` Returns the result of an expression. *`expr`* may be a code object ready for evaluation, or a string; if a string, `eval` gets a code object by internally calling `compile(`*`expr`*`, '<string>', 'eval')`. `eval` evaluates the code object as an expression, using the *`globals`* and *`locals`* dictionaries as namespaces (when they're missing, `eval` uses the current namespace). `eval` doesn't execute statements: it only evaluates expressions. Nevertheless, `eval` is dangerous; avoid it unless you know and trust that *`expr`* comes from a source that you are certain is safe. See also `ast.literal_eval` (covered in "Standard Input" on page 370), and "Dynamic Execution and exec" on page 430.

Core Built-ins and Modules

`exec`	`exec(statement[, globals[, locals]], /)` Like `eval`, but applies to any statement and returns **None**. `exec` is very dangerous, unless you know and trust that *`statement`* comes from a source that you are certain is safe. See also "Statements" on page 39 and "Dynamic Execution and exec" on page 430.

`filter`	`filter(func, seq, /)`
	Returns an iterator of those items of *`seq`* for which *`func`* is true. *`func`* can be any callable object accepting a single argument, or **None**. *`seq`* can be any iterable. When *`func`* is callable, `filter` calls *`func`* on each item of *`seq`*, just like the following generator expression:
	`(item for item in seq if func(item))`
	When *`func`* is **None**, `filter` tests for truthy items, just like:
	`(item for item in seq if item)`

`format`	`format(x, format_spec='', /)` Returns `x.__format__(format_spec)`. See Table 4-1.
`getattr`	`getattr(obj, name[, default], /)` Returns *`obj`*'s attribute named by string *`name`*. `getattr(obj, 'ident')` is like *`obj.ident`*. When *`default`* is present and *`name`* is not found in *`obj`*, `getattr` returns *`default`* instead of raising `AttributeError`. See also "Object attributes and items" on page 53 and "Attribute Reference Basics" on page 124.
`globals`	`globals()` Returns the `__dict__` of the calling module (i.e., the dictionary used as the global namespace at the point of call). See also `locals` later in this table. (Unlike `locals()`, the `dict` returned by `globals()` is read/write, and updates to that `dict` are equivalent to ordinary name definitions.)
`hasattr`	`hasattr(obj, name, /)` Returns **`False`** when *`obj`* has no attribute *`name`* (i.e., when `getattr(obj, name)` would raise `AttributeError`); otherwise, returns `True`. See also "Attribute Reference Basics" on page 124.
`hash`	`hash(obj, /)` Returns the hash value for *`obj`*. *`obj`* can be a dictionary key, or an item in a set, only if *`obj`* can be hashed. All objects that compare equal must have the same hash value, even if they are of different types. If the type of *`obj`* does not define equality comparison, `hash(obj)` normally returns `id(obj)` (see `id` in this table and `__hash__` in Table 4-1).
`help`	`help([obj, /])` When called without an *`obj`* argument, begins an interactive help session, which you exit by entering **`quit`**. When *`obj`* is given, `help` prints the documentation for *`obj`* and its attributes, and returns **None**. `help` is useful in interactive Python sessions to get a quick reference to an object's functionality.
`hex`	`hex(x, /)` Returns a hex string representation of `int` *`x`*. See also `__hex__` in Table 4-4.

`id`	`id(obj, /)` Returns the integer value that is the identity of *obj*. The `id` of *obj* is unique and constant during *obj*'s lifetime[a] (but may be reused at any later time after *obj* is garbage-collected, so don't rely on storing or checking `id` values). When a type or class does not define equality comparison, Python uses `id` to compare and hash instances. For any objects *x* and *y*, identity check *x* **is** *y* is the same as `id(x)==id(y)`, but more readable and better performing.
`input`	`input(prompt='', /)` Writes *prompt* to standard output, reads a line from standard input, and returns the line (without `\n`) as a `str`. At end-of-file, `input` raises `EOFError`.
`isinstance`	`isinstance(obj, cls, /)` Returns **True** when *obj* is an instance of class *cls* (or any subclass of *cls*, or implements protocol or ABC *cls*); otherwise, returns **False**. *cls* can be a tuple whose items are classes (or **3.10+** multiple types joined using the | operator): in this case, `isinstance` returns **True** when *obj* is an instance of any of the items of *cls*; otherwise, it returns **False**. See also "Abstract Base Classes" on page 150 and "Protocols" on page 179.
`issubclass`	`issubclass(cls1, cls2, /)` Returns **True** when *cls1* is a direct or indirect subclass of *cls2*, or defines all the elements of protocol or ABC *cls2*; otherwise, returns **False**. *cls1* and *cls2* must be classes. *cls2* can also be a tuple whose items are classes. In this case, `issubclass` returns **True** when *cls1* is a direct or indirect subclass of any of the items of *cls2*; otherwise, it returns **False**. For any class *C*, `issubclass(C, C)` returns **True**.

`iter`	`iter(obj, /)`,
	`iter(func, sentinel, /)`
	Creates and returns an iterator (an object that you can repeatedly pass to the `next` built-in function to get one item at a time; see "Iterators" on page 86). When called with one argument, `iter(obj)` normally returns `obj.__iter__()`. When *obj* is a sequence without a special method `__iter__`, `iter(obj)` is equivalent to the generator:
	`def iter_sequence(obj):`
	`    i = 0`
	`    while True:`
	`        try:`
	`            yield obj[i]`
	`        except IndexError:`
	`            raise StopIteration`
	`        i += 1`
	See also "Sequences" on page 43 and `__iter__` in Table 4-2.

`iter` *(cont.)*

When called with two arguments, the first argument must be callable without arguments, and `iter(func, sentinel)` is equivalent to the generator:

```
def iter_sentinel(func, sentinel):
    while True:
        item = func()
        if item == sentinel:
            raise StopIteration
        yield item
```

Don't Call iter in a for Clause

As discussed in "The for Statement" on page 84, the statement **`for`** *x* **`in`** *`obj`* is exactly equivalent to **`for`** *x* **`in`** `iter(`*`obj`*`)`; therefore, do *not* explicitly call `iter` in such a **`for`** statement. That would be redundant and, therefore, bad Python style, slower, and less readable.

`iter` is *idempotent*. In other words, when *x* is an iterator, `iter(`*`x`*`)` is *x*, as long as *x*'s class supplies an `__iter__` method whose body is just **`return`** `self`, as an iterator's class should.

`len`

`len(`*`container`*`, /)`
Returns the number of items in *`container`*, which may be a sequence, a mapping, or a set. See also `__len__` in "Container methods" on page 149.

`locals`

`locals()`
Returns a dictionary that represents the current local namespace. Treat the returned dictionary as read-only; trying to modify it may or may not affect the values of local variables, and might raise an exception. See also `globals` and `vars` in this table.

`map`

`map(`*`func`*`, `*`seq`*`, /)`,
`map(`*`func`*`, /, *`*`seqs`*`)`
`map` calls *`func`* on every item of iterable *`seq`* and returns an iterator of the results. When you call `map` with multiple *`seqs`* iterables, *`func`* must be a callable object that accepts *n* arguments (where *n* is the number of *`seqs`* arguments,). `map` repeatedly calls *`func`* with *n* arguments, one corresponding item from each iterable.
For example, `map(`*`func`*`, `*`seq`*`)` is just like the generator expression:

```
(func(item) for item in seq).map(func, seq1, seq2)
```

is just like the generator expression:

```
(func(a, b) for a, b in zip(seq1, seq2))
```

When `map`'s iterable arguments have different lengths, `map` acts as if the longer ones were truncated (just as `zip` itself does).

`max`

`max(`*`seq`*`, /, *, key=`**`None`**`[, default=...])`,
`max(*`*`args`*`, key=`**`None`**`[, default=...])`
Returns the largest item in the iterable argument *`seq`*, or the largest one of multiple positional arguments *`args`*. You can pass a `key` argument, with the same semantics covered in "Sorting a list" on page 68. You can also pass a `default` argument, the value to return if *`seq`* is empty; when you don't pass `default`, and *`seq`* is empty, `max` raises `ValueError`. (When you pass `key` and/or `default`, you must pass either or both as named arguments.)

min	`min(seq, /, *, key=None[, default=...])`, `min(*args, key=None[, default=...])` Returns the smallest item in the iterable argument *seq*, or the smallest one of multiple positional arguments *args*. You can pass a key argument, with the same semantics covered in "Sorting a list" on page 68. You can also pass a default argument, the value to return if *seq* is empty; when you don't pass default, and *seq* is empty, min raises ValueError. (When you pass key and/or default, you must pass either or both as named arguments.)
next	`next(it[, default], /)` Returns the next item from iterator *it*, which advances to the next item. When *it* has no more items, next returns *default*, or, when you don't pass *default*, raises StopIteration.
oct	`oct(x, /)` Converts int *x* to an octal string. See also `__oct__` in Table 4-4.
open	`open(file, mode='r', buffering=-1)` Opens or creates a file and returns a new file object. open accepts many, many more optional parameters; see "The io Module" on page 322 for details. open is one of the few built-ins callable with named arguments.
ord	`ord(ch, /)` Returns an int between 0 and sys.maxunicode (inclusive), corresponding to the single-character str argument *ch*. See also chr earlier in this table.
pow	`pow(x, y[, z], /)` When *z* is present, pow(*x*, *y*, *z*) returns (*x* ** *y*) % *z*. When *z* is missing, pow(*x*, *y*) returns *x* ** *y*. See also `__pow__` in Table 4-4. When *x* is an int and *y* is a nonnegative int, pow returns an int and uses Python's full value range for int (though evaluating pow for large *x* and *y* integer values may take some time). When either *x* or *y* is a float, or *y* is < 0, pow returns a float (or a complex, when x < 0 and y != int(y)); in this case, pow raises OverflowError if *x* or *y* is too large.
print	`print(/,*args, sep=' ', end='\n', file=sys.stdout, flush=False)` Formats with str, and emits to stream file, each item of *args* (if any), separated by sep, with end after all of them; then, print flushes the stream if flush is truthy.
range	`range([start=0, ]stop[, step=1], /)` Returns an iterator of ints in arithmetic progression: `start, start+step, start+(2*step), ...` When start is missing, it defaults to 0. When step is missing, it defaults to 1. When step is 0, range raises ValueError. When step is > 0, the last item is the largest start+(*i**step) strictly less than stop. When step is < 0, the last item is the smallest start+(*i**step) strictly greater than stop. The iterator is empty when start is greater than or equal to stop and step is greater than 0, or when start is less than or equal to stop and step is less than 0. Otherwise, the first item of the iterator is always start. When what you need is a list of ints in arithmetic progression, call list(range(...)).

repr	repr(*obj*, /) Returns a complete and unambiguous string representation of *obj*. When feasible, repr returns a string that you could pass to eval in order to create a new object with the same value as *obj*. See also str in Table 8-1 and __repr__ in Table 4-1.
reversed	reversed(*seq*, /) Returns a new iterator object that yields the items of *seq* (which must be specifically a sequence, not just any iterable) in reverse order.
round	round(number, ndigits=0) Returns a float whose value is int or float number rounded to ndigits digits after the decimal point (i.e., the multiple of 10**-ndigits that is closest to number). When two such multiples are equally close to number, round returns the *even* multiple. Since today's computers represent floating-point numbers in binary, not in decimal, most of round's results are not exact, as the tutorial in the docs explains in detail. See also "The decimal Module" on page 500 and David Goldberg's famous language-independent article on floating-point arithmetic.
setattr	setattr(*obj*, *name*, *value*, /) Binds *obj*'s attribute *name* to *value*. setattr(*obj*, '*ident*', *val*) is like *obj*.*ident*=*val*. See also getattr earlier in this table, "Object attributes and items" on page 53, and "Setting an attribute" on page 126.

sorted	sorted(*seq*, /, *, key=**None**, reverse=**False**)
	Returns a list with the same items as iterable *seq*, in sorted order. Same as:
	`def sorted(seq, /, *, key=None, reverse=False):`
	`    result = list(seq)`
	`    result.sort(key, reverse)`
	`    return result`
	See "Sorting a list" on page 68 for the meaning of the arguments. If you want to pass key and/or reverse, you *must* pass them by name.

sum	sum(*seq*, /, start=0) Returns the sum of the items of iterable *seq* (which should be numbers, and, in particular, cannot be strings) plus the value of start. When *seq* is empty, returns start. To "sum" (concatenate) an iterable of strings, in order, use ''.join(*iterofstrs*), as covered in Table 8-1 and "Building up a string from pieces" on page 554.
vars	vars([*obj*,]/) When called with no argument, vars returns a dictionary with all variables that are bound in the current scope (like locals, covered earlier in this table). Treat this dictionary as read-only. vars(*obj*) returns a dictionary with all attributes currently bound in *obj*, similar to dir, covered earlier in this table. This dictionary may be modifiable or not, depending on the type of *obj*.

zip	`zip(seq, /, *seqs, strict=False)` Returns an iterator of tuples, where the *n*th tuple contains the *n*th item from each of the argument iterables. You must call `zip` with at least one (positional) argument, and all positional arguments must be iterable. `zip` returns an iterator with as many items as the shortest iterable, ignoring trailing items in the other iterable objects. **3.10+** When the iterables have different lengths and `strict` is `True`, `zip` raises `ValueError` once it reaches the end of the shortest iterable. See also `map` earlier in this table and `zip_longest` in Table 8-10.

[a] Otherwise arbitrary; often, an implementation detail, *obj*'s address in memory.

The sys Module

The attributes of the `sys` module are bound to data and functions that provide information on the state of the Python interpreter or affect the interpreter directly. Table 8-3 covers the most frequently used attributes of `sys`. Most `sys` attributes we don't cover are meant specifically for use in debuggers, profilers, and integrated development environments; see the online docs for more information.

Platform-specific information is best accessed using the `platform` module, which we do not cover in this book; see the online docs for details on this module.

Table 8-3. Functions and attributes of the sys module

argv	The list of command-line arguments passed to the main script. `argv[0]` is the name of the main script,[a] or `'-c'` if the command line used the **-c** option. See "The argparse Module" on page 274 for one good way to use `sys.argv`.
audit	`audit(event, /, *args)` Raises an *audit event* whose name is `str` *event* and whose arguments are *args*. The rationale for Python's audit system is laid out in exhaustive detail in PEP 578; Python itself raises the large variety of events listed in the online docs. To *listen* for events, call `sys.addaudithook(hook)`, where *hook* is a callable whose arguments are a `str`, the event's name, followed by arbitrary positional arguments. For more details, see the docs.
builtin_ module_names	A tuple of `str`s: the names of all the modules compiled into this Python interpreter.

displayhook	`displayhook(value, /)`
	In interactive sessions, the Python interpreter calls `displayhook`, passing it the result of each expression statement you enter. The default `displayhook` does nothing when *value* is **None**; otherwise, it saves *value* in the built-in variable whose name is _ (an underscore) and displays it via `repr`:
	`def _default_sys_displayhook(value, /):`
	`    if value is not None:`
	`        __builtins__._ = value`
	`        print(repr(value))`
	You can rebind `sys.displayhook` in order to change interactive behavior. The original value is available as `sys.__displayhook__`.

dont_write_bytecode	When **True**, Python does not write a bytecode file (with extension *.pyc*) to disk when it imports a source file (with extension *.py*).
excepthook	excepthook(*type*, *value*, *traceback*, /) When an exception is not caught by any handler, propagating all the way up the call stack, Python calls excepthook, passing it the exception class, object, and traceback, as covered in "Exception Propagation" on page 204. The default excepthook displays the error and traceback. You can rebind sys.excepthook to change how uncaught exceptions (just before Python returns to the interactive loop or terminates) get displayed and/or logged. The original value is available as sys.__excepthook__.
exception	exception() **3.11+** When called within an **except** clause, returns the current exception instance (equivalent to sys.exc_info()[1]).
exc_info	exc_info() When the current thread is handling an exception, exc_info returns a tuple with three items: the class, object, and traceback for the exception. When the thread is not handling an exception, exc_info returns (**None**, **None**, **None**). To display information from a traceback, see "The traceback Module" on page 533.

Holding On to a Traceback Object Can Make Some Garbage Uncollectable

A traceback object indirectly holds references to all variables on the call stack; if you hold a reference to the traceback (e.g., indirectly, by binding a variable to the tuple that exc_info returns), Python must keep in memory data that might otherwise be garbage-collected. Make sure that any binding to the traceback object is of short duration, for example with a **try**/**finally** statement (discussed in "try/finally" on page 198). If you must hold a reference to an exception *e*, clear *e*'s traceback: *e*.__traceback__=**None**.[b]

exit	exit(*arg*=0, /) Raises a SystemExit exception, which normally terminates execution after executing cleanup handlers installed by **try**/**finally** statements, **with** statements, and the atexit module. When *arg* is an int, Python uses *arg* as the program's exit code: 0 indicates successful termination; any other value indicates unsuccessful termination of the program. Most platforms require exit codes to be between 0 and 127. When *arg* is not an int, Python prints *arg* to sys.stderr, and the exit code of the program is 1 (a generic "unsuccessful termination" code).
float_info	A read-only object whose attributes hold low-level details about the implementation of the float type in this Python interpreter. See the online docs for details.

`getrecursion limit`	`getrecursionlimit()` Returns the current limit on the depth of Python's call stack. See also "Recursion" on page 112 and `setrecursionlimit` later in this table.
`getrefcount`	`getrefcount(`*`obj`*`, /)` Returns the reference count of *`obj`*. Reference counts are covered in "Garbage Collection" on page 435.
`getsizeof`	`getsizeof(`*`obj`*`[, `*`default`*`], /)` Returns the size, in bytes, of *`obj`* (not counting any items or attributes *`obj`* may refer to), or *`default`* when *`obj`* does not provide a way to retrieve its size (in the latter case, when *`default`* is absent, `getsizeof` raises `TypeError`).
`maxsize`	The maximum number of bytes in an object in this version of Python (at least `2 ** 31 - 1`, that is, `2147483647`).
`maxunicode`	The largest codepoint for a Unicode character in this version of Python; currently, always `1114111` (`0x10FFFF`). The version of the Unicode database used by Python is in `unicodedata.unidata_version`.
`modules`	A dictionary whose items are the names and module objects for all loaded modules. See "Module Loading" on page 227 for more information on `sys.modules`.
`path`	A list of strings that specifies the directories and ZIP files that Python searches when looking for a module to load. See "Searching the Filesystem for a Module" on page 228 for more information on `sys.path`.
`platform`	A string that names the platform on which this program is running. Typical values are brief operating system names, such as `'darwin'`, `'linux2'`, and `'win32'`. For Linux, check `sys.platform.startswith('linux')`, for portability among Linux versions. See also the online docs for the module `platform`, which we don't cover in this book.

`ps1`, `ps2`	`ps1` and `ps2` specify the primary and secondary interpreter prompt strings, initially `>>>` and `...`, respectively. These `sys` attributes exist only in interactive interpreter sessions. If you bind either attribute to a non-`str` object *x*, Python prompts by calling `str(`*x*`)` on the object each time a prompt is output. This feature allows dynamic prompting: code a class that defines `__str__`, then assign an instance of that class to `sys.ps1` and/or `sys.ps2`. For example, to get numbered prompts:
	`>>> import sys`
	`>>> class Ps1(object):`
	`...     def __init__(self):`
	`...         self.p = 0`
	`...     def __str__(self):`
	`...         self.p += 1`
	`...         return f'[{self.p}]>>> '`
	`...`
	`>>> class Ps2(object):`
	`...     def __str__(self):`
	`...         return f'[{sys.ps1.p}]... '`
	`...`
	`>>> sys.ps1, sys.ps2 = Ps1(), Ps2()`
	`[1]>>> (2 +`
	`[1]... 2)`
	`4`
	`[2]>>>`

`setrecursion limit`	`setrecursionlimit(`*`limit`*`, /)` Sets the limit on the depth of Python's call stack (the default is `1000`). The limit prevents runaway recursion from crashing Python. Raising the limit may be necessary for programs that rely on deep recursion, but most platforms cannot support very large limits on call stack depth. More usefully, *lowering* the limit helps you check, during testing and debugging, that your program degrades gracefully, rather than abruptly crashing with a `RecursionError`, under situations of almost runaway recursion. See also "Recursion" on page 112 and `getrecursion limit` earlier in this table.
`stdin`, `stdout`, `stderr`	`stdin`, `stdout`, and `stderr` are predefined file-like objects that correspond to Python's standard input, output, and error streams. You can rebind `stdout` and `stderr` to file-like objects open for writing (objects that supply a `write` method accepting a string argument) to redirect the destination of output and error messages. You can rebind `stdin` to a file-like object open for reading (one that supplies a `readline` method returning a string) to redirect the source from which built-in function `input` reads. The original values are available as `__stdin__`, `__stdout__`, and `__stderr__`. We cover file objects in "The io Module" on page 322.
`tracebacklimit`	The maximum number of levels of traceback displayed for unhandled exceptions. By default, this attribute is not defined (i.e., there is no limit). When `sys.trace backlimit` is `<= 0`, Python prints only the exception type and value, without a traceback.

`version`	A string that describes the Python version, build number and date, and C compiler used. Use `sys.version` only for logging or interactive output; to perform version comparisons, use `sys.version_info`.
`version_info`	A `namedtuple` of the `major`, `minor`, `micro`, `releaselevel`, and `serial` fields of the running Python version. For example, in the first post-beta release of Python 3.10, `sys.version_info` was `sys.version_info(major=3, minor=10, micro=0, releaselevel='final', serial=0)`, equivalent to the tuple `(3, 10, 0, 'final', 0)`. This form is defined to be directly comparable between versions; to see if the current version running is greater than or equal to, say, 3.8, you can test `sys.version_info[:3] >= (3, 8, 0)`. (Do *not* do string comparisons of the *string* `sys.version`, since the string `"3.10"` would compare as less than `"3.9"`!)

[a] It could, of course, also be a path to the script, and/or a symbolic link to it, if that's what you gave Python.

[b] One of the book's authors had this very problem when memoizing return values and exceptions raised in `pyparsing`: the cached exception tracebacks held many object references and interfered with garbage collection. The solution was to clear the tracebacks of the exceptions before putting them in the cache.

The copy Module

As discussed in "Assignment Statements" on page 53, assignments in Python do not *copy* the righthand-side object being assigned. Rather, assignments *add references* to the RHS object. When you want a *copy* of object *x*, ask *x* for a copy of itself, or ask *x*'s type to make a new instance copied from *x*. If *x* is a list, `list(x)` returns a copy of *x*, as does `x[:]`. If *x* is a dictionary, `dict(x)` and `x.copy()` return a copy of *x*. If *x* is a set, `set(x)` and `x.copy()` return a copy of *x*. In each case, this book's authors prefer the uniform and readable idiom of calling the type, but there is no consensus on this style issue in the Python community.

The `copy` module supplies a `copy` function to create and return a copy of many types of objects. Normal copies, such as those returned by `list(x)` for a list *x* and `copy.copy(x)` for any *x*, are known as *shallow* copies: when *x* has references to other objects (either as items or as attributes), a normal (shallow) copy of *x* has distinct references to the *same* objects. Sometimes, however, you need a *deep* copy, where referenced objects are deep-copied recursively (fortunately, this need is rare, since a deep copy can take a lot of memory and time); for these cases, the `copy` module also supplies a `deepcopy` function. These functions are discussed further in Table 8-4.

Table 8-4. copy module functions

copy	`copy(x)` Creates and returns a shallow copy of *x*, for *x* of many types (modules, files, frames, and other internal types, however, are not supported). When *x* is immutable, `copy.copy(x)` may return *x* itself as an optimization. A class can customize the way `copy.copy` copies its instances by having a special method `__copy__(self)` that returns a new object, a shallow copy of `self`.

deepcopy	`deepcopy(x,[memo])`
	Makes a deep copy of *x* and returns it. Deep copying implies a recursive walk over a directed (but not necessarily acyclic) graph of references. Be aware that to reproduce the graph's exact shape, when references to the same object are met more than once during the walk, you must *not* make distinct copies; rather, you must use *references* to the same copied object. Consider the following simple example:
	`sublist = [1,2]`
	`original = [sublist, sublist]`
	`thecopy = copy.deepcopy(original)`
	`original[0] is original[1]` is **True** (i.e., the two items of `original` refer to the same object). This is an important property of `original`, and anything claiming to be "a copy" must preserve it. The semantics of `copy.deepcopy` ensure that `thecopy[0] is thecopy[1]` is also **True**: the graphs of references of `original` and `thecopy` have the same shape. Avoiding repeated copying has an important beneficial side effect: it prevents infinite loops that would otherwise occur when the graph of references has cycles.
	`copy.deepcopy` accepts a second, optional argument: `memo`, a `dict` that maps the `id` of each object already copied to the new object that is its copy. `memo` is passed by all recursive calls of `deepcopy` to itself; you may also explicitly pass it (normally as an originally empty `dict`) if you also need to obtain a correspondence map between the identities of originals and copies (the final state of `memo` will then be just such a mapping).
	A class can customize the way `copy.deepcopy` copies its instances by having a special method `__deepcopy__(self, memo)` that returns a new object, a deep copy of `self`. When `__deepcopy__` needs to deep-copy some referenced object *`subobject`*, it must do so by calling `copy.deepcopy(subobject, memo)`. When a class has no special method `__deepcopy__`, `copy.deepcopy` on an instance of that class also tries calling the special methods `__getinitargs__`, `__getnewargs__`, `__getstate__`, and `__setstate__`, covered in "Pickling instances" on page 393.

The collections Module

The `collections` module supplies useful types that are collections (i.e., containers), as well as the ABCs covered in "Abstract Base Classes" on page 150. Since Python 3.4, the ABCs have been in `collections.abc`; for backward compatibility they could still be accessed directly in `collections` itself until Python 3.9, but this functionality was removed in 3.10.

ChainMap

`ChainMap` "chains" multiple mappings together; given a `ChainMap` instance *c*, accessing *c*[*key*] returns the value in the first of the mappings that has that key, while *all* changes to *c* affect only the very first mapping in *c*. To further explain, you could approximate this as follows:

```
class ChainMap(collections.abc.MutableMapping):
    def __init__(self, *maps):
        self.maps = list(maps)
        self._keys = set()
        for m in self.maps:
            self._keys.update(m)
    def __len__(self): return len(self._keys)
    def __iter__(self): return iter(self._keys)
    def __getitem__(self, key):
        if key not in self._keys: raise KeyError(key)
        for m in self.maps:
            try: return m[key]
            except KeyError: pass
    def __setitem__(self, key, value):
        self.maps[0][key] = value
        self._keys.add(key)
    def __delitem__(self, key):
        del self.maps[0][key]
        self._keys = set()
        for m in self.maps:
            self._keys.update(m)
```

Other methods could be defined for efficiency, but this is the minimum set that a `MutableMapping` requires. See the online docs for more details and a collection of recipes on how to use `ChainMap`.

Counter

`Counter` is a subclass of `dict` with `int` values that are meant to *count* how many times a key has been seen (although values are allowed to be `<= 0`); it's roughly equivalent to types that other languages call "bag" or "multiset" types. A `Counter` instance is normally built from an iterable whose items are hashable: *c* = `collections.Counter(`*iterable*`)`. Then, you can index *c* with any of *iterable*'s items to get the number of times that item appeared. When you index *c* with any missing key, the result is `0` (to *remove* an entry in *c*, use **del** *c*[*entry*]; setting *c*[*entry*]`=0` leaves *entry* in *c*, with a value of `0`).

c supports all methods of `dict`; in particular, *c*`.update(`*otheriterable*`)` updates all the counts, incrementing them according to occurrences in *otheriterable*. So, for example:

```
>>> c = collections.Counter('moo')
>>> c.update('foo')
```

leaves c['o'] giving 4, and c['f'] and c['m'] each giving 1. Note that removing an entry from c (with **del**) may *not* decrement the counter, but subtract (described in the following table) does:

```
>>> del c['foo']
>>> c['o']
```

```
4
```

```
>>> c.subtract('foo')
>>> c['o']
```

```
2
```

In addition to dict methods, *c* supports the extra methods detailed in Table 8-5.

Table 8-5. Methods of a Counter instance c

elements	*c*.elements() Yields, in arbitrary order, keys in *c* with *c*[*key*]>0, yielding each key as many times as its count.
most_common	*c*.most_common([*n*, /]) Returns a list of pairs for the *n* keys in *c* with the highest counts (all of them, if you omit *n*), in order of decreasing count ("ties" between keys with the same count are resolved arbitrarily); each pair is of the form (*k*, *c*[*k*]), where *k* is one of the *n* most common keys in *c*.
subtract	*c*.subtract(*iterable*=**None**, /, ***kwds*) Like *c*.update(*iterable*) "in reverse"—that is, *subtracting* counts rather than *adding* them. Resulting counts in *c* can be <= 0.
total	*c*.total() **3.10+** Returns the sum of all the individual counts. Equivalent to sum(*c*.values()).

Counter objects support common arithmetic operators, such as +, -, &, and | for addition, subtraction, union, and intersection. See the online docs for more details and a collection of useful recipes on how to use Counter.

OrderedDict

OrderedDict is a subclass of dict with additional methods to access and manipulate items with respect to their insertion order. *o*.popitem() removes and returns the item at the most recently inserted key; *o*.move_to_end(*key*, last=**True**) moves the item with key *key* to the end (when last is **True**, the default) or to the start (when last is **False**). Equality tests between two instances of OrderedDict are order sensitive; equality tests between an instance of OrderedDict and a dict or other mapping are not. Since Python 3.7, dict insertion order is guaranteed to be maintained: many uses that previously required OrderedDict can now just use ordinary Python dicts. A significant difference remaining between the two is that OrderedDict's test for equality with other OrderedDicts is order sensitive, while dict's equality test is not. See the online docs for more details and a collection of recipes on how to use OrderedDict.

defaultdict

defaultdict extends dict and adds one per instance attribute, named default_factory. When an instance *d* of defaultdict has **None** as the value of *d*.default_factory, *d* behaves exactly like a dict. Otherwise, *d*.default_factory must be callable without arguments, and *d* behaves just like a dict except when you access *d* with a key *k* that is not in *d*. In this specific case, the indexing *d*[*k*] calls *d*.default_factory(), assigns the result as the value of *d*[*k*], and returns the result. In other words, the type defaultdict behaves much like the following Python-coded class:

```
class defaultdict(dict):
    def __init__(self, default_factory=None, *a, **k):
        super().__init__(*a, **k)
        self.default_factory = default_factory
    def __getitem__(self, key):
        if key not in self and self.default_factory is not None:
            self[key] = self.default_factory()
        return dict.__getitem__(self, key)
```

As this Python equivalent implies, to instantiate defaultdict you usually pass it an extra first argument (before any other arguments, positional and/or named, if any, to pass on to plain dict). The extra first argument becomes the initial value of default_factory; you can also access and rebind default_factory later, though doing so is infrequent in normal Python code.

All behavior of defaultdict is essentially as implied by this Python equivalent (except str and repr, which return strings different from those they would return for a dict). Named methods, such as get and pop, are not affected. All behavior related to keys (method keys, iteration, membership test via operator in, etc.) reflects exactly the keys that are currently in the container (whether you put them there explicitly, or implicitly via an indexing that called default_factory).

A typical use of defaultdict is, for example, to set default_factory to list, to make a mapping from keys to lists of values:

```
def make_multi_dict(items):
    d = collections.defaultdict(list)
    for key, value in items:
        d[key].append(value)
    return d
```

Called with any iterable whose items are pairs of the form (*key*, *value*), with all keys being hashable, this make_multi_dict function returns a mapping that associates each key to the lists of one or more values that accompanied it in the iterable (if you want a pure dict result, change the last statement into return dict(d)—this is rarely necessary).

If you don't want duplicates in the result, and every *value* is hashable, use a collections.defaultdict(set), and add rather than append in the loop.[2]

keydefaultdict

A variation on defaultdict that is *not* found in the collections module is a defaultdict whose default_factory takes the key as an initialization argument. This example shows how you can implement this for yourself:

```
class keydefaultdict(dict):
    def __init__(self, default_factory=None, *a, **k):
        super().__init__(*a, **k)
        self.default_factory = default_factory
    def __missing__(self, key):
        if self.default_factory is None:
            raise KeyError(key)
        self[key] = self.default_factory(key)
        return self[key]
```

The dict class supports the __missing__ method for subclasses to implement custom behavior when a key is accessed that is not yet in the dict. In this example, we implement __missing__ to call the default factory method with the new key, and add it to the dict. You can use keydefaultdict rather than defaultdict when the default_factory requires an argument (most often, this happens when the default factory is a class that takes an identifier constructor argument).

deque

deque is a sequence type whose instances are "double-ended queues" (additions and removals at either end are fast and thread-safe). A deque instance *d* is a mutable sequence, with an optional maximum length, and can be indexed and iterated on (however, *d* cannot be sliced; it can only be indexed one item at a time, whether for access, rebinding, or deletion). If a deque instance *d* has a maximum length, when items are added to either side of *d* so that *d*'s length exceeds that maximum, items are silently dropped from the other side.

deque is especially useful for implementing first-in, first-out (FIFO) queues.[3] deque is also good for maintaining "the latest *N* things seen," also known in some other languages as a *ring buffer*.

Table 8-6 lists the methods the deque type supplies.

2 When first introduced, defaultdict(int) was commonly used to maintain counts of items. Since Counter is now part of the collections module, use Counter instead of defaultdict(int) for the specific task of counting items.

3 For last-in, first-out (LIFO) queues, aka "stacks," a list, with its append and pop methods, is perfectly sufficient.

Table 8-6. deque methods

`deque`	`deque(`*`seq`*`=(), /, maxlen=`**`None`**`)` The initial items of *d* are those of *`seq`*, in the same order. *`d`*`.maxlen` is a read-only attribute: when its value is **`None`**, *d* has no maximum length; when an `int`, it must be `>=0`. *d*'s maximum length is *`d`*`.maxlen`.
`append`	*`d`*`.append(`*`item`*`, /)` Appends *`item`* at the right (end) of *d*.
`appendleft`	*`d`*`.appendleft(`*`item`*`, /)` Appends *`item`* at the left (start) of *d*.
`clear`	*`d`*`.clear()` Removes all items from *d*, leaving it empty.
`extend`	*`d`*`.extend(`*`iterable`*`, /)` Appends all items of *`iterable`* at the right (end) of *d*.
`extendleft`	*`d`*`.extendleft(`*`iterable`*`, /)` Appends all items of *`iterable`* at the left (start) of *d*, in reverse order.
`pop`	*`d`*`.pop()` Removes and returns the last (rightmost) item from *d*. If *d* is empty, raises `IndexError`.
`popleft`	*`d`*`.popleft()` Removes and returns the first (leftmost) item from *d*. If *d* is empty, raises `IndexError`.
`rotate`	*`d`*`.rotate(`*`n`*`=1, /)` Rotates *`d`* *`n`* steps to the right (if *`n`*`<0`, rotates left).

Avoid Indexing or Slicing a deque

`deque` is primarily intended for cases that access, add, and remove items from either the `deque`'s start or end. While indexing or slicing into a `deque` is possible, it may only have `O(n)` performance (vs `O(1)` for `list`) when accessing an inner value using `deque[i]` form. If you must access inner values, consider using a `list` instead.

The functools Module

The `functools` module supplies functions and types supporting functional programming in Python, listed in Table 8-7.

Table 8-7. Functions and attributes of the `functools` module

`cached_property`	`cached_property(func)` **3.8+** A caching version of the `property` decorator. Evaluating the property the first time caches the returned value, so that subsequent calls can return the cached value instead of repeating the property calculation. `cached_property` uses a threading lock to ensure that the property calculation is performed only once, even in a multithreaded environment.[a]

lru_cache, cache	lru_cache(max_size=128, typed=**False**), cache() A *memoizing* decorator suitable for decorating a function whose arguments are all hashable, adding to the function a cache storing the last max_size results (max_size should be a power of 2, or **None** to have the cache keep all previous results); when you call the decorated function again with arguments that are in the cache, it immediately returns the previously cached result, bypassing the underlying function's body code. When typed is **True**, arguments that compare equal but have different types, such as 23 and 23.0, are cached separately. **3.9+** If setting max_size to **None**, use cache instead. For more details and examples, see the online docs. **3.8+** lru_cache may also be used as a decorator with no ().

partial	partial(*func*, /, **a*, ***k*)
	Returns a callable *p* that is just like *func* (which is any callable), but with some positional and/or named parameters already bound to the values given in *a* and *k*. In other words, *p* is a *partial application* of *func*, often also known (with debatable correctness, but colorfully, in honor of mathematician Haskell Curry) as a *currying* of *func* to the given arguments. For example, say that we have a list of numbers L and want to clip the negative ones to 0. One way to do it is:
	`L = map(functools.partial(max, 0), L)`
	as an alternative to the **lambda**-using snippet:
	`L = map(lambda x: max(0, x), L)`
	and to the most concise approach, a list comprehension:
	`L = [max(0, x) for x in L]`
	functools.partial comes into its own in situations that demand callbacks, such as event-driven programming for some GUIs and networking applications.
	partial returns a callable with the attributes func (the wrapped function), args (the tuple of prebound positional arguments), and keywords (the dict of prebound named arguments, or **None**).

reduce	reduce(*func*, *seq*[, *init*], /)
	Applies *func* to the items of *seq*, from left to right, to reduce the iterable to a single value. *func* must be callable with two arguments. reduce calls *func* on the first two items of *seq*, then on the result of the first call and the third item, and so on, and returns the result of the last such call. When *init* is present, reduce uses it before *seq*'s first item, if any. When *init* is missing, *seq* must be nonempty. When *init* is missing and *seq* has only one item, reduce returns *seq*[0]. Similarly, when *init* is present and *seq* is empty, reduce returns *init*. reduce is thus roughly equivalent to:
	`def reduce_equiv(func, seq, init=None):`
	`    seq = iter(seq)`
	`    if init is None:`
	`        init = next(seq)`
	`    for item in seq:`
	`        init = func(init, item)`
	`    return init`
	An example use of reduce is to compute the product of a sequence of numbers:
	`prod=reduce(operator.mul, seq, 1)`

`singledispatch`, `singledispatchmethod`	Function decorators to support multiple implementations of a method with differing types for their first argument. See the online docs for a detailed description.
`total_ordering`	A class decorator suitable for decorating classes that supply at least one inequality comparison method, such as `__lt__`, and, ideally, also supply `__eq__`. Based on the class's existing methods, the class decorator `total_ordering` adds to the class all other inequality comparison methods that aren't implemented in the class itself or any of its superclasses, removing the need for you to add boilerplate code for them.
`wraps`	`wraps(wrapped)` A decorator suitable for decorating functions that wrap another function, `wrapped` (often nested functions within another decorator). `wraps` copies the `__name__`, `__doc__`, and `__module__` attributes of `wrapped` on the decorated function, thus improving the behavior of the built-in function `help`, and of doctests, covered in "The doctest Module" on page 517.

[a] In Python versions 3.8 to 3.11, `cached_property` is implemented using a class-level lock. As such, it synchronizes for all instances of the class or any subclass, not just the current instance. Thus, `cached_property` can reduce performance in a multithreaded environment, and is *not* recommended.

The heapq Module

The `heapq` module uses *min-heap* algorithms to keep a list in "nearly sorted" order as items are inserted and extracted. `heapq`'s operation is faster than calling a list's `sort` method after each insertion, and much faster than `bisect` (covered in the online docs). For many purposes, such as implementing "priority queues," the nearly sorted order supported by `heapq` is just as good as a fully sorted order, and faster to establish and maintain. The `heapq` module supplies the functions listed in Table 8-8.

Table 8-8. Functions of the `heapq` module

`heapify`	`heapify(alist, /)`
	Permutes `list` *`alist`* as needed to make it satisfy the (min) heap condition:
	For any *i* `>= 0`:
	`alist[i] <= alist[2 * i + 1]` and
	`alist[i] <= alist[2 * i + 2]`
	as long as all the indices in question are `<len(alist)`.
	If a `list` satisfies the (min) heap condition, the list's first item is the smallest (or equal-smallest) one. A sorted `list` satisfies the heap condition, but many other permutations of a list also satisfy the heap condition without requiring the list to be fully sorted. `heapify` runs in `O(len(alist))` time.

Core Built-ins and Modules

heappop	heappop(*alist*, /) Removes and returns the smallest (first) item of *alist*, a list that satisfies the heap condition, and permutes some of the remaining items of *alist* to ensure the heap condition is still satisfied after the removal. heappop runs in O(log(len(*alist*))) time.
heappush	heappush(*alist*, *item*, /) Inserts *item* in *alist*, a list that satisfies the heap condition, and permutes some items of *alist* to ensure the heap condition is still satisfied after the insertion. heappush runs in O(log(len(*alist*))) time.

heappushpop	heappushpop(*alist*, *item*, /)
	Logically equivalent to heappush followed by heappop, similar to:
	`def heappushpop(alist, item):`
	`    heappush(alist, item)`
	`    return heappop(alist)`
	heappushpop runs in O(log(len(*alist*))) time and is generally faster than the logically equivalent function just shown. heappushpop can be called on an empty *alist*: in that case, it returns the *item* argument, as it does when *item* is smaller than any existing item of *alist*.

heapreplace	heapreplace(*alist*, *item*, /)
	Logically equivalent to heappop followed by heappush, similar to:
	`def heapreplace(alist, item):`
	`    try: return heappop(alist)`
	`    finally: heappush(alist, item)`
	heapreplace runs in O(log(len(*alist*))) time and is generally faster than the logically equivalent function just shown. heapreplace cannot be called on an empty *alist*: heapreplace always returns an item that was already in *alist*, never the *item* just being pushed onto it.

merge	merge(**iterables*) Returns an iterator yielding, in sorted order (smallest to largest), the items of the *iterables*, each of which must be smallest-to-largest sorted.
nlargest	nlargest(*n*, *seq*, /, key=**None**) Returns a reverse-sorted list with the *n* largest items of iterable *seq* (or less than *n* if *seq* has fewer than *n* items); like sorted(*seq*, reverse=**True**)[:*n*], but faster when *n* is "small enough"[a] compared to len(*seq*). You may also specify a (named or positional) key= argument, like you can for sorted.
nsmallest	nsmallest(*n*, *seq*, /, key=**None**) Returns a sorted list with the *n* smallest items of iterable *seq* (or less than *n* if *seq* has fewer than *n* items); like sorted(*seq*)[:*n*], but faster when *n* is "small enough" compared to len(*seq*). You may also specify a (named or positional) key= argument, like you can for sorted.

[a] To find out how specific values of *n* and len(*seq*) affect the timing of nlargest, nsmallest, and sorted on your specific Python version and machine, use timeit, covered in "The timeit module" on page 552.

The Decorate–Sort–Undecorate Idiom

Several functions in the `heapq` module, although they perform comparisons, do not accept a `key=` argument to customize the comparisons. This is inevitable, since the functions operate in place on a plain `list` of the items: they have nowhere to "stash away" custom comparison keys computed once and for all.

When you need both heap functionality and custom comparisons, you can apply the good old *decorate–sort–undecorate (DSU)* idiom[4] (which used to be crucial to optimize sorting in ancient versions of Python, before the `key=` functionality was introduced).

The DSU idiom, as applied to `heapq`, has the following components:

Decorate
: Build an auxiliary list *A* where each item is a tuple starting with the sort key and ending with the item of the original list *L*.

Sort
: Call `heapq` functions on *A*, typically starting with `heapq.heapify(A)`.[5]

Undecorate
: When you extract an item from *A*, typically by calling `heapq.heappop(A)`, return just the last item of the resulting tuple (which was an item of the original list *L*).

When you add an item to *A* by calling `heapq.heappush(A, /, item)`, decorate the actual item you're inserting into a tuple starting with the sort key.

This sequence of operations can be wrapped up in a class, as in this example:

```
import heapq

class KeyHeap(object):
    def __init__(self, alist, /, key):
        self.heap = [(key(o), i, o) for i, o in enumerate(alist)]
        heapq.heapify(self.heap)
        self.key = key
        if alist:
            self.nexti = self.heap[-1][1] + 1
        else:
            self.nexti = 0

    def __len__(self):
        return len(self.heap)

    def push(self, o, /):
```

Core Built-ins and Modules

4 Also known as the *Schwartzian transform*.

5 This step is not *quite* a full "sort," but it looks close enough to call it one, at least if you squint.

```
            heapq.heappush(self.heap, (self.key(o), self.nexti, o))
            self.nexti += 1

        def pop(self):
            return heapq.heappop(self.heap)[-1]
```

In this example, we use an increasing number in the middle of the decorated tuple (after the sort key, before the actual item) to ensure that actual items are *never* compared directly, even if their sort keys are equal (this semantic guarantee is an important aspect of the `key` argument's functionality for `sort` and the like).

The argparse Module

When you write a Python program meant to be run from the command line (or from a shell script in Unix-like systems, or a batch file in Windows), you often want to let the user pass to the program, on the command line or within the script, *command-line arguments* (including *command-line options*, which by convention are arguments starting with one or two dash characters). In Python, you can access the arguments as `sys.argv`, an attribute of the module `sys` holding those arguments as a list of strings (`sys.argv[0]` is the name or path by which the user started your program; the arguments are in the sublist `sys.argv[1:]`). The Python standard library offers three modules to process those arguments; we only cover the newest and most powerful one, `argparse`, and we only cover a small, *core* subset of `argparse`'s rich functionality. See the online reference and tutorial for much, much more. `argparse` provides one class, which has the following signature:

`Argument Parser`	`ArgumentParser(**`*`kwargs`*`)` `ArgumentParser` is the class whose instances perform argument parsing. It accepts many named arguments, mostly meant to improve the help message that your program displays if command-line arguments include `-h` or `--help`. One named argument you should always pass is `description=`, a string summarizing the purpose of your program.

Given an instance *ap* of `ArgumentParser`, prepare it with one or more calls to *ap*`.add_argument`, then use it by calling *ap*`.parse_args()` without arguments (so it parses `sys.argv`). The call returns an instance of `argparse.Namespace`, with your program's arguments and options as attributes.

`add_argument` has a mandatory first argument: an identifier string for positional command-line arguments, or a flag name for command-line options. In the latter case, pass one or more flag names; an option can have both a short name (dash, then a character) and a long name (two dashes, then an identifier).

After the positional arguments, pass to `add_argument` zero or more named arguments to control its behavior. Table 8-9 lists the most commonly used ones.

Table 8-9. Common named arguments to `add_argument`

`action`	What the parser does with this argument. Default: `'store'`, which stores the argument's value in the namespace (at the name given by `dest`, described later in this table). Also useful: `'store_true'` and `'store_false'`, making an option into a `bool` (defaulting to the opposite `bool` if the option is not present), and `'append'`, appending argument values to a list (and thus allowing an option to be repeated).
`choices`	A set of values allowed for the argument (parsing the argument raises an exception if the value is not among these). Default: no constraints.
`default`	Value if the argument is not present. Default: **None**.
`dest`	Name of the attribute to use for this argument. Default: same as the first positional argument stripped of leading dashes, if any.
`help`	A `str` describing the argument, for help messages.
`nargs`	The number of command-line arguments used by this logical argument. Default: `1`, stored in the namespace. Can be an `int > 0` (uses that many arguments, stores them as a list), `'?'` (`1` or none, in which case it uses `default`), `'*'` (`0` or more, stored as a list), `'+'` (`1` or more, stored as a list), or `argparse.REMAINDER` (all remaining arguments, stored as a list).
`type`	A callable accepting a string, often a type such as `int`; used to transform values from strings to something else. Can be an instance of `argparse.FileType` to open the string as a filename (for reading if `FileType('r')`, for writing if `FileType('w')`, and so on).

Here's a simple example of `argparse`—save this code in a file called *greet.py*:

```
import argparse
ap = argparse.ArgumentParser(description='Just an example')
ap.add_argument('who', nargs='?', default='World')
ap.add_argument('--formal', action='store_true')
ns = ap.parse_args()
if ns.formal:
    greet = 'Most felicitous salutations, o {}.'
else:
    greet = 'Hello, {}!'
print(greet.format(ns.who))
```

Now, **`python greet.py`** prints `Hello, World!`, while **`python greet.py --formal Cornelia`** prints `Most felicitous salutations, o Cornelia`.

The itertools Module

The `itertools` module offers high-performance building blocks to build and manipulate iterators. To handle long processions of items, iterators are often better than lists, thanks to the iterators' intrinsic "lazy evaluation" approach: an iterator produces items one at a time, as needed, while all items of a list (or other sequence) must be in memory at the same time. This approach even makes it feasible to build and use unbounded iterators, while lists must always have finite numbers of items (since any machine has a finite amount of memory).

Table 8-10 covers the most frequently used attributes of `itertools`; each of them is an iterator type, which you call to get an instance of the type in question, or a factory function behaving similarly. See the online docs for more `itertools` attributes, including *combinatorial* generators for permutations, combinations, and Cartesian products, as well as a useful taxonomy of `itertools` attributes.

The online docs also offer recipes describing ways to combine and use `itertools` attributes. The recipes assume you have `from itertools import *` at the top of your module; this is *not* recommended use, just an assumption to make the recipes' code more compact. It's best to `import itertools as it`, then use references such as `it.`*`something`* rather than the more verbose `itertools.`*`something`*.[6]

Table 8-10. Functions and attributes of the `itertools` module

`accumulate`	`accumulate(`*`seq`*`, `*`func`*`, /[, initial=`*`init`*`])` Similar to `functools.reduce(`*`func`*`, `*`seq`*`)`, but returns an iterator of all the intermediate computed values, not just the final value. **3.8+** You can also pass an initial value *`init`*, which works the same way as in `functools.reduce` (see Table 8-7).

`chain`	`chain(*`*`iterables`*`)`
	Yields items from the first argument, then items from the second argument, and so on, until the end of the last argument. This is just like the generator expression:
	`(it for iterable in iterables for it in iterable)`

`chain.from_iterable`	`chain.from_iterable(`*`iterables`*`, /)`
	Yields items from the iterables in the argument, in order, just like the genexp:
	`(it for iterable in iterables for it in iterable)`

`compress`	`compress(`*`data`*`, `*`conditions`*`, /)`
	Yields each item from *`data`* corresponding to a true item in *`conditions`*, just like the genexp:
	`(it for it, cond in zip(data, conditions) if cond)`

`count`	`count(start=0, step=1)`
	Yields consecutive integers starting from *`start`*, just like the generator:
	`def count(start=0, step=1):`
	`    while True:`
	`        yield start`
	`        start += step`
	`count` returns an unending iterator, so use it carefully, always ensuring you explicitly terminate any loop over it.

6 Some experts recommend `from itertools import *`, but the authors of this book disagree.

`cycle`	`cycle(iterable, /)`	

`cycle` — `cycle(`*`iterable`*`, /)`

Yields each item of *`iterable`*, endlessly repeating items from the beginning each time it reaches the end, just like the generator:

```
def cycle(iterable):
    saved = []
    for item in iterable:
        yield item
        saved.append(item)
    while saved:
        for item in saved:
            yield item
```

`cycle` returns an unending iterator, so use it carefully, always ensuring you explicitly terminate any loop over it.

`dropwhile` — `dropwhile(`*`func`*`, `*`iterable`*`, /)`

Drops the `0+` leading items of *`iterable`* for which *`func`* is true, then yields each remaining item, just like the generator:

```
def dropwhile(func, iterable):
    iterator = iter(iterable)
    for item in iterator:
        if not func(item):
            yield item
            break
    for item in iterator:
        yield item
```

`filterfalse` — `filterfalse(`*`func`*`, `*`iterable`*`, /)`

Yields those items of *`iterable`* for which *`func`* is false, just like the genexp:

```
(it for it in iterable if not func(it))
```

`func` can be any callable accepting a single argument, or **None**. When *`func`* is **None**, `filterfalse` yields false items, just like the genexp:

```
(it for it in iterable if not it)
```

`groupby`	`groupby(`*`iterable`*`, /, key=`**`None`**`)`
	`iterable` normally needs to be already sorted according to `key` (**None**, as usual, standing for the identity function, **`lambda`** `x: x`). `groupby` yields pairs `(`*`k`*`, `*`g`*`)`, each pair representing a *group* of adjacent items from *`iterable`* having the same value *`k`* for *`key`*`(`*`item`*`)`; each *`g`* is an iterator yielding the items in the group. When the `groupby` object advances, previous iterators *`g`* become invalid (so, if a group of items needs to be processed later, you'd better store somewhere a `list` "snapshot" of it, `list(`*`g`*`)`).
	Another way of looking at the groups `groupby` yields is that each terminates as soon as *`key`*`(`*`item`*`)` changes (which is why you normally call `groupby` only on an *`iterable`* that's already sorted by *`key`*).
	For example, suppose that, given a `set` of lowercase words, we want a `dict` that maps each initial to the longest word having that initial (with "ties" broken arbitrarily). We could write:
	`import itertools as it`
	`import operator`
	`def set2dict(aset):`
	`    first = operator.itemgetter(0)`
	`    words = sorted(aset, key=first)`
	`    adict = {}`
	`    for init, group in it.groupby(words, key=first):`
	`        adict[init] = max(group, key=len)`
	`    return adict`

`islice`	`islice(`*`iterable`*`[, `*`start`*`], `*`stop`*`[, `*`step`*`], /)`
	Yields items of *`iterable`* (skipping the first *`start`* ones, by default `0`) up to but not including *`stop`*, advancing by steps of *`step`* (default `1`) at a time. All arguments must be nonnegative integers (or **None**), and *`step`* must be `> 0`. Apart from checks and optional arguments, it's like the generator:
	`def islice(iterable, start, stop, step=1):`
	`    en = enumerate(iterable)`
	`    n = stop`
	`    for n, item in en:`
	`        if n>=start:`
	`            break`
	`    while n<stop:`
	`        yield item`
	`        for x in range(step):`
	`            n, item = next(en)`

`pairwise`	`pairwise(`*`seq`*`, /)` **3.10+** Yields pairs of items in *`seq`*, with overlap (for example, `pairwise('ABCD')` will yield `'AB'`, `'BC'`, and `'CD'`). Equivalent to the iterator returned from `zip(`*`seq`*`, `*`seq`*`[1:])`.

repeat	repeat(*item*, /[, times])
	Repeatedly yields *item*, just like the genexp:
	`(item for _ in range(times))`
	When times is absent, the iterator is unbounded, yielding a potentially infinite number of items, each of which is the object *item*, just like the generator:
	`def repeat_unbounded(item):`
	`    while True:`
	`        yield item`

starmap	starmap(*func*, *iterable*, /)
	Yields func(**item*) for each *item* in *iterable* (each such *item* must be an iterable, normally a tuple), just like the generator:
	`def starmap(func, iterable):`
	`    for item in iterable:`
	`        yield func(*item)`

takewhile	takewhile(*func*, *iterable*, /)
	Yields items from *iterable* as long as *func*(*item*) is truthy, then finishes, just like the generator:
	`def takewhile(func, iterable):`
	`    for item in iterable:`
	`        if func(item):`
	`            yield item`
	`        else:`
	`            break`

tee	tee(*iterable*, *n*=2, /) Returns a tuple of *n* independent iterators, each yielding items that are the same as those of *iterable*. The returned iterators are independent from each other, but they are *not* independent from *iterable*; avoid altering the object *iterable* in any way, as long as you're still using any of the returned iterators.
zip_longest	zip_longest(**iterables*, /, fillvalue=**None**) Yields tuples with one corresponding item from each of the *iterables*; stops when the longest of the *iterables* is exhausted, behaving as if each of the others was "padded" to that same length with references to fillvalue. If **None** is a value that might be valid in one or more of the *iterables* (such that it could be confused with **None** values used for padding), you can use a Python Ellipsis (...) or a sentinel object FILL=object() for fillvalue.

We have shown equivalent generators and genexps for many attributes of itertools, but it's important to take into account the sheer speed of itertools. As a trivial example, consider repeating some action 10 times:

```
for _ in itertools.repeat(None, 10): pass
```

This turns out to be about 10 to 20% faster, depending on the Python release and platform, than the straightforward alternative:

```
for _ in range(10): pass
```

9
Strings and Things

Python's `str` type implements Unicode text strings with operators, built-in functions, methods, and dedicated modules. The somewhat similar `bytes` type represents arbitrary binary data as a sequence of bytes, also known as a *bytestring* or *byte string*. Many textual operations are possible on objects of either type: since these types are immutable, methods mostly create and return a new string unless returning the subject string unchanged. A mutable sequence of bytes can be represented as a `bytearray`, briefly introduced in "bytearray objects" on page 47.

This chapter first covers the methods available on these three types, then discusses the string module and string formatting (including formatted string literals), followed by the `textwrap`, `pprint`, and `reprlib` modules. Issues related specifically to Unicode are covered at the end of the chapter.

Methods of String Objects

`str`, `bytes`, and `bytearray` objects are sequences, as covered in "Strings" on page 44; of these, only `bytearray` objects are mutable. All immutable-sequence operations (repetition, concatenation, indexing, and slicing) apply to instances of all three types, returning a new object of the same type. Unless otherwise specified in Table 9-1, methods are present on objects of all three types. Most methods of `str`, `bytes`, and `bytearray` objects return values of the same type, or are specifically intended to convert among representations.

Terms such as "letters," "whitespace," and so on refer to the corresponding attributes of the `string` module, covered in the following section. Although `bytearray` objects are mutable, their methods returning a `bytearray` result do not mutate the object but instead return a newly created `bytearray`, even when the result is the same as the subject string.

For brevity, the term bytes in the following table refers to both bytes and bytearray objects. Take care when mixing these two types, however: while they are generally interoperable, the type of the result usually depends on the order of the operands.

In Table 9-1, since integer values in Python can be arbitrarily large, for conciseness we use sys.maxsize for integer default values to mean, in practice, "integer of unlimited magnitude."

Table 9-1. Significant str and bytes methods

capitalize	*s*.capitalize() Returns a copy of *s* where the first character, if a letter, is uppercase, and all other letters, if any, are lowercase.
casefold	*s*.casefold() **str only**. Returns a string processed by the algorithm described in section 3.13 of the Unicode standard. This is similar to *s*.lower (described later in this table) but also takes into account equivalences such as that between the German 'ß' and 'ss', and is thus better for case-insensitive matching when working with text that can include more than just the basic ASCII characters.
center	*s*.center(*n*, *fillchar*=' ', /) Returns a string of length max(len(*s*), *n*), with a copy of *s* in the central part, surrounded by equal numbers of copies of character *fillchar* on both sides. The default fillchar is a space. For example, 'ciao'.center(2) is 'ciao' and 'x'.center(4, '_') is '_x__'.
count	*s*.count(*sub*, *start*=0, *end*=sys.maxsize, /) Returns the number of nonoverlapping occurrences of substring *sub* in *s*[*start*:*end*].
decode	*s*.decode(encoding='utf-8', errors='strict') **bytes only**. Returns a str object decoded from the bytes *s* according to the given encoding. errors specifies how to handle decoding errors: 'strict' causes errors to raise UnicodeError exceptions; 'ignore' ignores the malformed values, while 'replace' replaces them with question marks (see "Unicode" on page 301 for details). Other values can be registered via codecs.register_error, covered in Table 9-10.
encode	*s*.encode(encoding='utf-8', errors='strict') **str only**. Returns a bytes object obtained from str *s* with the given encoding and error handling. See "Unicode" on page 301 for more details.
endswith	*s*.endswith(*suffix*, *start*=0, *end*=sys.maxsize, /) Returns **True** when *s*[*start*:*end*] ends with the string *suffix*; otherwise, returns **False**. *suffix* can be a tuple of strings, in which case endswith returns **True** when *s*[*start*:*end*] ends with any one of them.
expandtabs	*s*.expandtabs(tabsize=8) Returns a copy of *s* where each tab character is changed into one or more spaces, with tab stops every *tabsize* characters.

`find`	*s*.find(*sub*, *start*=0, *end*=sys.maxsize, /) Returns the lowest index in *s* where substring *sub* is found, such that *sub* is entirely contained in *s*[*start*:*end*]. For example, 'banana'.find('na') returns 2, as does 'banana'.find('na', 1), while 'banana'.find('na', 3) returns 4, as does 'banana'.find('na', -2). find returns -1 when *sub* is not found.
`format`	*s*.format(**args*, ***kwargs*) **str only**. Formats the positional and named arguments according to formatting instructions contained in the string *s*. See "String Formatting" on page 287 for further details.
`format_map`	*s*.format_map(mapping) **str only**. Formats the mapping argument according to formatting instructions contained in the string *s*. Equivalent to *s*.format(**mapping) but uses the mapping directly. See "String Formatting" on page 287 for formatting details.
`index`	*s*.index(*sub*, *start*=0, *end*=sys.maxsize, /) Like find, but raises ValueError when *sub* is not found.
`isalnum`	*s*.isalnum() Returns **True** when len(*s*) is greater than 0 and all characters in *s* are Unicode letters or digits. When *s* is empty, or when at least one character of *s* is neither a letter nor a digit, isalnum returns **False**.
`isalpha`	*s*.isalpha() Returns **True** when len(*s*) is greater than 0 and all characters in *s* are letters. When *s* is empty, or when at least one character of *s* is not a letter, isalpha returns **False**.
`isascii`	*s*.isascii() Returns **True** when the string is empty or all characters in the string are ASCII, or **False** otherwise. ASCII characters have codepoints in the range U+0000–U+007F.
`isdecimal`	*s*.isdecimal() **str only**. Returns **True** when len(*s*) is greater than 0 and all characters in *s* can be used to form decimal-radix numbers. This includes Unicode characters defined as Arabic digits.[a]
`isdigit`	*s*.isdigit() Returns **True** when len(*s*) is greater than 0 and all characters in *s* are Unicode digits. When *s* is empty, or when at least one character of *s* is not a Unicode digit, isdigit returns **False**.
`isidentifier`	*s*.isidentifier() **str only**. Returns **True** when *s* is a valid identifier according to the Python language's definition; keywords also satisfy the definition, so, for example, 'class'.isidentifier() returns **True**.
`islower`	*s*.islower() Returns **True** when all letters in *s* are lowercase. When *s* contains no letters, or when at least one letter of *s* is uppercase, islower returns **False**.

Strings and Things

isnumeric	*s*.isnumeric() **str only**. Similar to *s*.isdigit(), but uses a broader definition of numeric characters that includes all characters defined as numeric in the Unicode standard (such as fractions).
isprintable	*s*.isprintable() **str only**. Returns **True** when all characters in *s* are spaces ('\x20') or are defined in the Unicode standard as printable. Because the null string contains no unprintable characters, ''.isprintable() returns **True**.
isspace	*s*.isspace() Returns **True** when len(*s*) is greater than 0 and all characters in *s* are whitespace. When *s* is empty, or when at least one character of *s* is not whitespace, isspace returns **False**.
istitle	*s*.istitle() Returns **True** when the string *s* is *titlecased*: i.e., with a capital letter at the start of every contiguous sequence of letters, and all other letters lowercase (e.g., 'King Lear'.istitle() returns **True**). When *s* contains no letters, or when at least one letter of *s* violates the title case condition, istitle returns **False** (e.g., '1900'.istitle() and 'Troilus and Cressida'.istitle() return **False**).
isupper	*s*.isupper() Returns **True** when all letters in *s* are uppercase. When *s* contains no letters, or when at least one letter of *s* is lowercase, isupper returns **False**.
join	*s*.join(*seq*, /) Returns the string obtained by concatenating the items of *seq* separated by copies of *s* (e.g., ''.join(str(x) **for** x **in** range(7)) returns '0123456' and 'x'.join('aeiou') returns 'axexixoxu').
ljust	*s*.ljust(*n*, *fillchar*=' ', /) Returns a string of length max(len(*s*),*n*), with a copy of *s* at the start, followed by zero or more trailing copies of character *fillchar*.
lower	*s*.lower() Returns a copy of *s* with all letters, if any, converted to lowercase.
lstrip	*s*.lstrip(*x*=string.whitespace, /) Returns a copy of *s* after removing any leading characters found in string *x*. For example, 'banana'.lstrip('ab') returns 'nana'.
removeprefix	*s*.removeprefix(*prefix*, /) **3.9+** When *s* begins with *prefix*, returns the remainder of *s*; otherwise, returns *s*.
removesuffix	*s*.removesuffix(*suffix*, /) **3.9+** When *s* ends with *suffix*, returns the rest of *s*; otherwise, returns *s*.
replace	*s*.replace(*old*, *new*, *count*=sys.maxsize, /) Returns a copy of *s* with the first *count* (or fewer, if there are fewer) nonoverlapping occurrences of substring *old* replaced by string *new* (e.g., 'banana'.replace('a', 'e', 2) returns 'benena').

`rfind`	`s.rfind(sub, start=0, end=sys.maxsize, /)` Returns the highest index in *s* where substring *sub* is found, such that *sub* is entirely contained in `s[start:end]`. `rfind` returns `-1` if *sub* is not found.
`rindex`	`s.rindex(sub, start=0, end=sys.maxsize, /)` Like `rfind`, but raises `ValueError` if *sub* is not found.
`rjust`	`s.rjust(n, fillchar=' ', /)` Returns a string of length `max(len(s),n)`, with a copy of *s* at the end, preceded by zero or more leading copies of character *fillchar*.
`rstrip`	`s.rstrip(x=string.whitespace, /)` Returns a copy of *s*, removing trailing characters that are found in string *x*. For example, `'banana'.rstrip('ab')` returns `'banan'`.

`split`	`s.split(sep=None, maxsplit=sys.maxsize)`
	 Returns a list *L* of up to `maxsplit+1` strings. Each item of *L* is a "word" from *s*, where string `sep` separates words. When *s* has more than `maxsplit` words, the last item of *L* is the substring of *s* that follows the first `maxsplit` words. When `sep` is **None**, any string of whitespace separates words (e.g., `'four score and seven years'.split(None, 3)` returns `['four', 'score', 'and', 'seven years']`).
	 Note the difference between splitting on **None** (any run of whitespace characters is a separator) and splitting on `' '` (where each single space character, *not* other whitespace such as tabs and newlines, and *not* strings of spaces, is a separator). For example:
	 `>>> x = 'a  bB'   # two spaces between a and bB`
	 `>>> x.split()     # or x.split(None)`
	 `['a', 'bB']`
	 `>>> x.split(' ')`
	 `['a', '', 'bB']`
	 In the first case, the two-spaces string in the middle is a single separator; in the second case, each single space is a separator, so that there is an empty string between the two spaces.

`splitlines`	`s.splitlines(keepends=False)` Like `s.split('\n')`. When `keepends` is **True**, however, the trailing `'\n'` is included in each item of the resulting list (except the last one, if *s* does not end with `'\n'`).
`startswith`	`s.startswith(prefix, start=0, end=sys.maxsize, /)` Returns **True** when `s[start:end]` starts with string *prefix*; otherwise, returns **False**. *prefix* can be a tuple of strings, in which case `startswith` returns **True** when `s[start:end]` starts with any one of them.
`strip`	`s.strip(x=string.whitespace, /)` Returns a copy of *s*, removing both leading and trailing characters that are found in string *x*. For example, `'banana'.strip('ab')` returns `'nan'`.
`swapcase`	`s.swapcase()` Returns a copy of *s* with all uppercase letters converted to lowercase and vice versa.

`title`	`s.title()` Returns a copy of *s* transformed to title case: a capital letter at the start of each contiguous sequence of letters, with all other letters (if any) lowercase.

`translate`	`s.translate(table, /, delete=b'')`
	Returns a copy of *s*, where characters found in *table* are translated or deleted. When *s* is a `str`, you cannot pass the argument `delete`; *table* is a `dict` whose keys are Unicode ordinals and whose values are Unicode ordinals, Unicode strings, or **None** (to delete the corresponding character). For example:
	`tbl = {ord('a'):None, ord('n'):'ze'}`
	`print('banana'.translate(tbl))  # prints: 'bzeze'`
	When *s* is a `bytes`, *table* is a `bytes` object of length 256; the result of `s.translate(t, b)` is a `bytes` object with each item *b* of *s* omitted if *b* is one of the items of `delete`, and otherwise changed to `t[ord(b)]`.
	`bytes` and `str` each have a class method named `maketrans` which you can use to build tables suitable for the respective `translate` methods.

`upper`	`s.upper()` Returns a copy of *s* with all letters, if any, converted to uppercase.

[a] This does *not* include punctuation marks used as a radix, such as a dot (`.`) or comma (`,`).

The string Module

The `string` module supplies several useful string attributes, listed in Table 9-2.

Table 9-2. Predefined constants in the `string` module

`ascii_letters`	The string `ascii_lowercase+ascii_uppercase` (the following two constants, concatenated)
`ascii_lowercase`	The string `'abcdefghijklmnopqrstuvwxyz'`
`ascii_uppercase`	The string `'ABCDEFGHIJKLMNOPQRSTUVWXYZ'`
`digits`	The string `'0123456789'`
`hexdigits`	The string `'0123456789abcdefABCDEF'`
`octdigits`	The string `'01234567'`
`punctuation`	The string `'!"#$%&\'()*+,-./:;<=>?@[\]^_'{|}~'` (i.e., all ASCII characters that are deemed punctuation characters in the C locale; does not depend on which locale is active)
`printable`	The string of those ASCII characters that are deemed printable (i.e., digits, letters, punctuation, and whitespace)
`whitespace`	A string containing all ASCII characters that are deemed whitespace: at least space, tab, linefeed, and carriage return, but more characters (e.g., certain control characters) may be present, depending on the active locale

You should not rebind these attributes; the effects of doing so are undefined, since other parts of the Python library may rely on them.

The module `string` also supplies the class `Formatter`, covered in the following section.

String Formatting

Python provides a flexible mechanism for formatting strings (but *not* bytestrings: for those, see "Legacy String Formatting with %" on page 297). A *format string* is simply a string containing *replacement fields* enclosed in braces (`{}`), made up of a *value part*, an optional *conversion part*, and an optional *format specifier*:

```
{value-part[!conversion-part][:format-specifier]}
```

The value part differs depending on the string type:

- For formatted string literals, or *f-strings*, the value part is evaluated as a Python expression (see the following section for details); expressions cannot end in an exclamation mark.
- For other strings, the value part selects an argument, or an element of an argument, to the `format` method.

The optional conversion part is an exclamation mark (`!`) followed by one of the letters `s`, `r`, or `a` (described in "Value Conversion" on page 290).

The optional format specifier begins with a colon (`:`) and determines how the converted value is rendered for interpolation in the format string in place of the original replacement field.

Formatted String Literals (F-Strings)

This feature allows you to insert values to be interpolated inline surrounded by braces. To create a formatted string literal, put an `f` before the opening quote mark (this is why they're called *f-strings*) of your string, e.g., `f'{value}'`:

```
>>> name = 'Dawn'
>>> print(f'{name!r} is {len(name)} characters long')
'Dawn' is 4 characters long
```

You can use nested braces to specify components of formatting expressions:

```
>>> for width in 8, 11:
...     for precision in 2, 3, 4, 5:
...         print(f'{2.7182818284:{width}.{precision}}')
...
     2.7
    2.72
   2.718
  2.7183
        2.7
       2.72
```

Strings and Things

```
 2.718
2.7183
```

We have tried to update most of the examples in the book to use f-strings, since they are the most compact way to format strings in Python. Do remember, though, that these string literals are *not* constants—they evaluate each time a statement containing them is executed, which involves runtime overhead.

The values to be formatted inside formatted string literals are already inside quotes: therefore, take care to avoid syntax errors when using value-part expressions that themselves contain string quotes. With four different string quotes, plus the ability to use escape sequences, most things are possible, though admittedly readability can suffer.

> **F-Strings Don't Help Internationalization**
> Given a format whose contents will have to accommodate multiple languages, it's much better to use the `format` method, since the values to be interpolated can then be computed independently before submitting them for formatting.

Debug printing with f-strings

3.8+ As a convenience for debugging, the last nonblank character of the value expression in a formatted string literal can be followed by an equals sign (=), optionally surrounded by spaces. In this case the text of the expression itself and the equals sign, including any leading and trailing spaces, are output before the value. In the presence of the equals sign, when no format is specified, Python uses the `repr()` of the value as output; otherwise, Python uses the `str()` of the value unless an `!r` value conversion is specified:

```
>>> a = '*-'
>>> s = 12
>>> f'{a*s=}'
"a*s='*-*-*-*-*-*-*-*-*-*-*-*-'"
>>> f'{a*s = :30}'
'a*s = *-*-*-*-*-*-*-*-*-*-*-*-      '
```

Note that this form is *only* available in formatted string literals.

Here's a simple f-string example. Notice that all text, including any whitespace, surrounding the replacement fields is copied literally into the result:

```
>>> n = 10
>>> s = ('zero', 'one', 'two', 'three')
>>> i = 2
>>> f'start {"-"*n} : {s[i]} end'
'start ---------- : two end'
```

Formatting Using format Calls

The same formatting operations available in formatted string literals can also be performed by a call to the string's `format` method. In these cases, rather than the value appearing inline, the replacement field begins with a value part that selects an argument of that call. You can specify both positional and named arguments. Here's an example of a simple `format` method call:

```
>>> name = 'Dawn'
>>> print('{name} is {n} characters long'
... .format(name=name, n=len(name)))
```

```
'Dawn' is 4 characters long
```

```
>>> "This is a {1}, {0}, type of {type}".format("green", "large",
...                                           type="vase")
```

```
'This is a large, green, type of vase'
```

For simplicity, none of the replacement fields in this example contain a conversion part or a format specifier.

As mentioned previously, the argument selection mechanism when using the `format` method can handle both positional and named arguments. The simplest replacement field is the empty pair of braces (`{}`), representing an *automatic* positional argument specifier. Each such replacement field automatically refers to the value of the next positional argument to `format`:

```
>>> 'First: {} second: {}'.format(1, 'two')
```

```
'First: 1 second: two'
```

To repeatedly select an argument, or use it out of order, use numbered replacement fields to specify the argument's position in the list of arguments (counting from zero):

```
>>> 'Second: {1}, first: {0}'.format(42, 'two')
```

```
'Second: two, first: 42'
```

You cannot mix automatic and numbered replacement fields: it's an either-or choice.

For named arguments, use argument names. If desired, you can mix them with (automatic or numbered) positional arguments:

```
>>> 'a: {a}, 1st: {}, 2nd: {}, a again: {a}'.format(1, 'two', a=3)
```

```
'a: 3, 1st: 1, 2nd: two, a again: 3'
```

```
>>> 'a: {a} first:{0} second: {1} first: {0}'.format(1, 'two', a=3)
```

```
'a: 3 first:1 second: two first: 1'
```

If an argument is a sequence, you can use numeric indices to select a specific element of the argument as the value to be formatted. This applies to both positional (automatic or numbered) and named arguments:

```
>>> 'p0[1]: {[1]} p1[0]: {[0]}'.format(('zero', 'one'),
...                                     ('two', 'three'))
'p0[1]: one p1[0]: two'
>>> 'p1[0]: {1[0]} p0[1]: {0[1]}'.format(('zero', 'one'),
...                                       ('two', 'three'))
'p1[0]: two p0[1]: one'
>>> '{} {} {a[2]}'.format(1, 2, a=(5, 4, 3))
'1 2 3'
```

If an argument is a composite object, you can select its individual attributes as values to be formatted by applying attribute-access dot notation to the argument selector. Here is an example using complex numbers, which have `real` and `imag` attributes that hold the real and imaginary parts, respectively:

```
>>> 'First r: {.real} Second i: {a.imag}'.format(1+2j, a=3+4j)
'First r: 1.0 Second i: 4.0'
```

Indexing and attribute-selection operations can be used multiple times, if required.

Value Conversion

You may apply a default conversion to the value via one of its methods. You indicate this by following any selector with `!s` to apply the object's `__str__` method, `!r` for its `__repr__` method, or `!a` for the `ascii` built-in:

```
>>> "String: {0!s} Repr: {0!r} ASCII: {0!a}".format("banana 😀")
"String: banana 😀 Repr: 'banana 😀' ASCII: 'banana\\U0001f600'"
```

When a conversion is present, the conversion is applied to the value before it is formatted. Since the same value is required multiple times, in this example a `format` call makes much more sense than a formatted string literal, which would require the value to be repeated three times.

Value Formatting: The Format Specifier

The final (optional) portion of the replacement field, known as the *format specifier* and introduced by a colon (:), provides any further required formatting of the (possibly converted) value. The absence of a colon in the replacement field means that the converted value (after representation as a string if not already in string form) is used with no further formatting. If present, a format specifier should be provided conforming to the syntax:

```
[[fill]align][sign][z][#][0][width][grouping_option][.precision][type]
```

Details are provided in the following subsections.

Fill and alignment

The default fill character is the space. To use an alternative fill character (which cannot be an opening or closing brace), begin the format specifier with the fill character. The fill character, if any, should be followed by an *alignment indicator* (see Table 9-3).

Table 9-3. Alignment indicators

Character	Significance as alignment indicator
`'<'`	Align value on left of field
`'>'`	Align value on right of field
`'^'`	Align value at center of field
`'='`	Only for numeric types: add fill characters between the sign and the first digit of the numeric value

If the first and second characters are *both* valid alignment indicators, then the first is used as the fill character and the second is used to set the alignment.

When no alignment is specified, values other than numbers are left-aligned. Unless a field width is specified later in the format specifier (see "Field width" on page 293), no fill characters are added, whatever the fill and alignment may be:

```
>>> s = 'a string'
>>> f'{s:>12s}'
'    a string'
>>> f'{s:>>12s}'
'>>>>a string'
>>> f'{s:><12s}'
'a string>>>>'
```

Sign indication

For numeric values only, you can indicate how positive and negative numbers are differentiated by including a sign indicator (see Table 9-4).

Table 9-4. Sign indicators

Character	Significance as sign indicator
`'+'`	Insert `+` as sign for positive numbers; `-` as sign for negative numbers
`'-'`	Insert `-` as sign for negative numbers; do not insert any sign for positive numbers (default behavior if no sign indicator is included)
`' '`	Insert a space character as sign for positive numbers; `-` as sign for negative numbers

The space is the default sign indication. If a fill is specified, it will appear between the sign, if any, and the numerical value; place the sign indicator *after* the = to avoid it being used as a fill character:

```
>>> n = -1234
>>> f'{n:12}'    # 12 spaces before the number
'       -1234'
>>> f'{-n:+12}'  # - to flip n's sign, + as sign indicator
'       +1234'
>>> f'{n:+=12}'  # + as fill character between sign and number
'-+++++++1234'
# + as sign indicator, spaces fill between sign and number
>>> f'{n:=+12}'
'-       1234'
# * as fill between sign and number, + as sign indicator
>>> f'{n:*=+12}'
'-*******1234'
```

Zero normalization (z)

3.11+ Some numeric formats are capable of representing a negative zero, which is often a surprising and unwelcome result. Such negative zeros will be normalized to positive zeros when a `z` character appears in this position in the format specifier:

```
>>> x = -0.001
>>> f'{x:.1f}'
'-0.0'
>>> f'{x:z.1f}'
'0.0'
>>> f'{x:+z.1f}'
'+0.0'
```

Radix indicator (#)

For numeric *integer* formats only, you can include a radix indicator, the `#` character. If present, this indicates that the digits of binary-formatted numbers should be preceded by `'0b'`, those of octal-formatted numbers by `'0o'`, and those of hexadecimal-formatted numbers by `'0x'`. For example, `'{23:x}'` is `'17'`, while `'{23:#x}'` is `'0x17'`, clearly identifying the value as hexadecimal.

Leading zero indicator (0)

For *numeric types only*, when the field width starts with a zero, the numeric value will be padded with leading zeros rather than leading spaces:

```
>>> f"{-3.1314:12.2f}"
'       -3.13'
>>> f"{-3.1314:012.2f}"
'-00000003.13'
```

Field width

You can specify the width of the field to be printed. If the width specified is less than the length of the value, the length of the value is used (but for string values, see the upcoming section "Precision specification"). If alignment is not specified, the value is left justified (except for numbers, which are right justified):

```
>>> s = 'a string'
>>> f'{s:^12s}'
'  a string  '
>>> f'{s:.>12s}'
'....a string'
```

Using nested braces, when calling the `format` method, the field width can be a format argument too:

```
>>> '{:.>{}s}'.format(s, 20)
'............a string'
```

See "Nested Format Specifications" on page 295 for a fuller discussion of this technique.

Grouping option

For numeric values in the decimal (default) format type, you can insert either a comma (,) or an underscore (_) to request that each group of three digits (*digit group*) in the integer portion of the result be separated by that character. For example:

```
>>> f'{12345678.9:,}'
'12,345,678.9'
```

This behavior ignores system locale; for a locale-aware use of digit grouping and decimal point character, see format type `n` in Table 9-5.

Precision specification

The precision (e.g., `.2`) has different meanings for different format types (see the following subsection for details), with `.6` as the default for most numeric formats. For the `f` and `F` format types, it specifies the number of digits following the decimal point to which the value should be rounded in formatting; for the `g` and `G` format types, it specifies the number of *significant* digits to which the value should be *rounded*; for nonnumeric values, it specifies *truncation* of the value to its leftmost characters before formatting. For example:

```
>>> x = 1.12345
>>> f'as f: {x:.4f}'  # rounds to 4 digits after decimal point
'as f: 1.1235'
>>> f'as g: {x:.4g}'  # rounds to 4 significant digits
'as g: 1.123'
>>> f'as s: {"1234567890":.6s}'  # string truncated to 6 characters
'as s: 123456'
```

Format type

The format specification ends with an optional *format type*, which determines how the value gets represented in the given width and at the given precision. In the absence of an explicit format type, the value being formatted determines the default format type.

The `s` format type is always used to format Unicode strings.

Integer numbers have a range of acceptable format types, listed in Table 9-5.

Table 9-5. Integer format types

Format type	Formatting description
b	Binary format—a series of ones and zeros
c	The Unicode character whose ordinal value is the formatted value
d	Decimal (the default format type)
n	Decimal format, with locale-specific separators (commas in the UK and US) when system locale is set
o	Octal format—a series of octal digits
x or X	Hexadecimal format—a series of hexadecimal digits, with the letters, respectively, in lower- or uppercase

Floating-point numbers have a different set of format types, shown in Table 9-6.

Table 9-6. Floating-point format types

Format type	Formatting description
e or E	Exponential format—scientific notation, with an integer part between one and nine, using e or E just before the exponent
f or F	Fixed-point format with infinities (inf) and nonnumbers (nan) in lower- or uppercase
g or G	General format (the default format type)—uses a fixed-point format when possible, otherwise exponential format; uses lower- or uppercase representations for e, inf, and nan, depending on the case of the format type
n	Like general format, but uses locale-specific separators, when system locale is set, for groups of three digits and decimal points
%	Percentage format—multiplies the value by 100 and formats it as fixed-point followed by %

When no format type is specified, a float uses the g format, with at least one digit after the decimal point and a default precision of 12.

The following code takes a list of numbers and displays each right justified in a field width of nine characters; it specifies that each number's sign will always display, adds a comma between each group of three digits, and rounds each number to exactly two digits after the decimal point, converting ints to floats as needed:

```
>>> for num in [3.1415, -42, 1024.0]:
...     f'{num:>+9,.2f}'
...
'    +3.14'
'   -42.00'
'+1,024.00'
```

Nested Format Specifications

In some cases you'll want to use expression values to help determine the precise format used: you can use nested formatting to achieve this. For example, to format a string in a field four characters wider than the string itself, you can pass a value for the width to format, as in:

```
>>> s = 'a string'
>>> '{0:>{1}s}'.format(s, len(s)+4)
'    a string'
>>> '{0:_^{1}s}'.format(s, len(s)+4)
'__a string__'
```

With some care, you can use width specification and nested formatting to print a sequence of tuples into well-aligned columns. For example:

```
def columnar_strings(str_seq, widths):
    for cols in str_seq:
        row = [f'{c:{w}.{w}s}'
```

```
                for c, w in zip(cols, widths)]
        print(' '.join(row))
```

Given this function, the following code:

```
    c = [
            'four score and'.split(),
            'seven years ago'.split(),
            'our forefathers brought'.split(),
            'forth on this'.split(),
        ]

    columnar_strings(c, (8, 8, 8))
```

prints:

```
four     score    and
seven    years    ago
our      forefath brought
forth    on       this
```

Formatting of User-Coded Classes

Values are ultimately formatted by a call to their `__format__` method with the format specifier as an argument. Built-in types either implement their own method or inherit from `object`, whose rather unhelpful `format` method only accepts an empty string as an argument:

```
>>> object().__format__('')

'<object object at 0x110045070>'

>>> import math
>>> math.pi.__format__('18.6')

'           3.14159'
```

You can use this knowledge to implement an entirely different formatting mini-language of your own, should you so choose. The following simple example demonstrates the passing of format specifications and the return of a (constant) formatted string result. The interpretation of the format specification is under your control, and you may choose to implement whatever formatting notation you choose:

```
>>> class S:
...     def __init__(self, value):
...         self.value = value
...     def __format__(self, fstr):
...         match fstr:
...             case 'U':
...                 return self.value.upper()
...             case 'L':
...                 return self.value.lower()
...             case 'T':
...                 return self.value.title()
...             case _:
```

```
...                 return ValueError(f'Unrecognized format code'
...                                   f' {fstr!r}')
>>> my_s = S('random string')
>>> f'{my_s:L}, {my_s:U}, {my_s:T}'
```

```
'random string, RANDOM STRING, Random String'
```

The return value of the `__format__` method is substituted for the replacement field in the formatted output, allowing any desired interpretation of the format string.

This technique is used in the `datetime` module, to allow the use of `strftime`-style format strings. Consequently, the following all give the same result:

```
>>> import datetime
>>> d = datetime.datetime.now()
>>> d.__format__('%d/%m/%y')
```

```
'10/04/22'
```

```
>>> '{:%d/%m/%y}'.format(d)
```

```
'10/04/22'
```

```
>>> f'{d:%d/%m/%y}'
```

```
'10/04/22'
```

To help you format your objects more easily, the `string` module provides a `Formatter` class with many helpful methods for handling formatting tasks. See the online docs for details.

Legacy String Formatting with %

A legacy form of string formatting expression in Python has the syntax:

```
format % values
```

where *`format`* is a `str`, `bytes`, or `bytearray` object containing format specifiers, and *`values`* are the values to format, usually as a tuple.[1] Unlike Python's newer formatting capabilities, you can also use `%` formatting with `bytes` and `bytearray` objects, not just `str` ones.

The equivalent use in `logging` would be, for example:

```
logging.info(format, *values)
```

with the *`values`* coming as positional arguments after the *`format`*.

The legacy string-formatting approach has roughly the same set of features as the C language's `printf` and operates in a similar way. Each format specifier is a substring

1 In this book we cover only a subset of this legacy feature, the format specifier, that you must know about to properly use the `logging` module (discussed in "The logging module" on page 217).

of *format* that starts with a percent sign (%) and ends with one of the conversion characters shown in Table 9-7.

Table 9-7. String-formatting conversion characters

Character	Output format	Notes
d, i	Signed decimal integer	Value must be a number
u	Unsigned decimal integer	Value must be a number
o	Unsigned octal integer	Value must be a number
x	Unsigned hexadecimal integer (lowercase letters)	Value must be a number
X	Unsigned hexadecimal integer (uppercase letters)	Value must be a number
e	Floating-point value in exponential form (lowercase e for exponent)	Value must be a number
E	Floating-point value in exponential form (uppercase E for exponent)	Value must be a number
f, F	Floating-point value in decimal form	Value must be a number
g, G	Like e or E when *exp* is >=4 or < precision; otherwise, like f or F	*exp* is the exponent of the number being converted
a	String	Converts any value with ascii
r	String	Converts any value with repr
s	String	Converts any value with str
%	Literal % character	Consumes no value

The a, r, and s conversion characters are the ones most often used with the logging module. Between the % and the conversion character, you can specify a number of optional modifiers, as we'll discuss shortly.

What is logged with a formatting expression is *format*, where each format specifier is replaced by the corresponding item of *values* converted to a string according to the specifier. Here are some simple examples:

```
import logging
logging.getLogger().setLevel(logging.INFO)
x = 42
y = 3.14
z = 'george'
logging.info('result = %d', x)          # logs: result = 42
logging.info('answers: %d %f', x, y)  # logs: answers: 42 3.140000
logging.info('hello %s', z)            # logs: hello george
```

Format Specifier Syntax

Each format specifier corresponds to an item in *values* by position. A format specifier can include modifiers to control how the corresponding item in *values* is converted to a string. The components of a format specifier, in order, are:

- The mandatory leading % character that marks the start of the specifier
- Zero or more optional conversion flags:

  '#'
  : The conversion uses an alternate form (if any exists for its type).

  '0'
  : The conversion is zero padded.

  '-'
  : The conversion is left justified.

  ' '
  : Negative numbers are signed, and a space is placed before a positive number.

  '+'
  : A numeric sign (+ or -) is placed before any numeric conversion.

- An optional minimum width of the conversion: one or more digits, or an asterisk (*), meaning that the width is taken from the next item in *values*
- An optional precision for the conversion: a dot (.) followed by zero or more digits or by a *, meaning that the precision is taken from the next item in *values*
- A mandatory conversion type from Table 9-7

There must be exactly as many *values* as *format* has specifiers (plus one extra for each width or precision given by *). When a width or precision is given by *, the * consumes one item in *values*, which must be an integer and is taken as the number of characters to use as the width or precision of that conversion.

Always Use %r (or %a) to Log Possibly Erroneous Strings

Most often, the format specifiers in your *`format`* string will all be `%s`; occasionally, you'll want to ensure horizontal alignment of the output (for example, in a right-justified, maybe truncated space of exactly six characters, in which case you'd use `%6.6s`). However, there is an important special case for `%r` or `%a`.

When you're logging a string value that might be erroneous (for example, the name of a file that is not found), don't use `%s`: when the error is that the string has spurious leading or trailing spaces, or contains some nonprinting characters such as `\b`, `%s` can make this hard for you to spot by studying the logs. Use `%r` or `%a` instead, so that all characters are clearly shown, possibly via escape sequences. (For f-strings, the corresponding syntax would be `{variable!r}` or `{variable!a}`).

Text Wrapping and Filling

The `textwrap` module supplies a class and a few functions to format a string by breaking it into lines of a given maximum length. To fine-tune the filling and wrapping, you can instantiate the `TextWrapper` class supplied by `textwrap` and apply detailed control. Most of the time, however, one of the functions exposed by `textwrap` suffices; the most commonly used functions are covered in Table 9-8.

Table 9-8. Useful functions of the `textwrap` module

`dedent`	`dedent(text)` Takes a multiline string and returns a copy in which all lines have had the same amount of leading whitespace removed, so that some lines have no leading whitespace.
`fill`	`fill(text, width=70)` Returns a single multiline string equal to `'\n'.join(wrap(text, width))`.
`wrap`	`wrap(text, width=70)` Returns a list of strings (without terminating newlines), each no longer than `width` characters. `wrap` also supports other named arguments (equivalent to attributes of instances of class `TextWrapper`); for such advanced uses, see the online docs.

The pprint Module

The `pprint` module pretty-prints data structures, with formatting that strives to be more readable than that supplied by the built-in function `repr` (covered in Table 8-2). To fine-tune the formatting, you can instantiate the `PrettyPrinter` class supplied by `pprint` and apply detailed control, helped by auxiliary functions also supplied by `pprint`. Most of the time, however, one of the functions exposed by `pprint` suffices (see Table 9-9).

Table 9-9. Useful functions of the `pprint` module

pformat	`pformat(object)` Returns a string representing the pretty-printing of `object`.

pp,
pprint
	`pp(object, stream=`*`sys.stdout`*`)`,
	`pprint(object, stream=`*`sys.stdout`*`)`
	Outputs the pretty-printing of `object` to open-for-writing file object `stream`, with a terminating newline.
	The following statements do exactly the same thing:
	`print(pprint.pformat(x))`
	`pprint.pprint(x)`
	Either of these constructs is roughly the same as `print(`*`x`*`)` in many cases—for example, for a container that can be displayed within a single line. However, with something like *`x`*`=list(range(30))`, `print(`*`x`*`)` displays *x* in 2 lines, breaking at an arbitrary point, while using the module `pprint` displays x over 30 lines, one line per item. Use `pprint` when you prefer the module's specific display effects to the ones of normal string representation.
	`pprint` and pp support additional formatting arguments; consult the online docs for details.

The reprlib Module

The `reprlib` module supplies an alternative to the built-in function `repr` (covered in Table 8-2), with limits on length for the representation string. To fine-tune the length limits, you can instantiate or subclass the `Repr` class supplied by the `reprlib` module and apply detailed control. Most of the time, however, the only function exposed by the module suffices: `repr(`*`obj`*`)`, which returns a string representing *`obj`*, with sensible limits on length.

Unicode

To convert bytestrings into Unicode strings, use the `decode` method of bytestrings (see Table 9-1). The conversion must always be explicit, and is performed using an auxiliary object known as a *codec* (short for *coder–decoder*). A codec can also convert Unicode strings to bytestrings using the `encode` method of strings. To identify a codec, pass the codec name to `decode` or `encode`. When you pass no codec name, Python uses a default encoding, normally `'utf-8'`.

Every conversion has a parameter `errors`, a string specifying how conversion errors are to be handled. Sensibly, the default is `'strict'`, meaning any error raises an exception. When `errors` is `'replace'`, the conversion replaces each character causing errors with `'?'` in a bytestring result, or with `u'\ufffd'` in a Unicode result. When `errors` is `'ignore'`, the conversion silently skips characters causing errors. When `errors` is `'xmlcharrefreplace'`, the conversion replaces each character causing errors with the XML character reference representation of that character in the result. You may code your own function to implement a conversion error handling strategy and register it under an appropriate name by calling `codecs.register_error`, covered in the table in the following section.

The codecs Module

The mapping of codec names to codec objects is handled by the `codecs` module. This module also lets you develop your own codec objects and register them so that they can be looked up by name, just like built-in codecs. It provides a function that lets you look up any codec explicitly as well, obtaining the functions the codec uses for encoding and decoding, as well as factory functions to wrap file-like objects. Such advanced facilities are rarely used, and we do not cover them in this book.

The `codecs` module, together with the `encodings` package of the standard Python library, supplies built-in codecs useful to Python developers dealing with internationalization issues. Python comes with over 100 codecs; you can find a complete list, with a brief explanation of each, in the online docs. It's *not* good practice to install a codec as the site-wide default in the module `sitecustomize`; rather, the preferred usage is to always specify the codec by name whenever converting between byte and Unicode strings. Python's default Unicode encoding is `'utf-8'`.

The `codecs` module supplies codecs implemented in Python for most ISO 8859 encodings, with codec names from `'iso8859-1'` to `'iso8859-15'`. A popular codec in Western Europe is `'latin-1'`, a fast, built-in implementation of the ISO 8859-1 encoding that offers a one-byte-per-character encoding of special characters found in Western European languages (beware that it lacks the Euro currency character `'€'`; however, if you need that, use `'iso8859-15'`). On Windows systems only, the codec named `'mbcs'` wraps the platform's multibyte character set conversion procedures. The `codecs` module also supplies various code pages with names from `'cp037'` to `'cp1258'`, and Unicode standard encodings `'utf-8'` (likely to be most often the best choice, thus recommended, and the default) and `'utf-16'` (which has specific big-endian and little-endian variants: `'utf-16-be'` and `'utf-16-le'`). For use with UTF-16, `codecs` also supplies attributes `BOM_BE` and `BOM_LE`, byte-order marks for big-endian and little-endian machines, respectively, and `BOM`, the byte-order mark for the current platform.

In addition to various functions for more advanced uses, as mentioned earlier, the `codecs` module supplies a function to let you register your own conversion error handling functions:

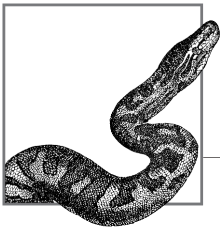
`register_error`	`register_error(`*`name`*`, `*`func`*`, /)` *`name`* must be a string. *`func`* must be callable with one argument *`e`* that is an instance of `UnicodeDecodeError`, and must return a tuple with two items: the Unicode string to insert in the converted string result, and the index from which to continue the conversion (the latter is normally *`e`*`.end`). The function can use *`e`*`.encoding`, the name of the codec of this conversion, and *`e`*`.object[`*`e`*`.start:`*`e`*`.end]`, the substring causing the conversion error.

The unicodedata Module

The `unicodedata` module provides easy access to the Unicode Character Database. Given any Unicode character, you can use functions supplied by `unicodedata` to obtain the character's Unicode category, official name (if any), and other relevant information. You can also look up the Unicode character (if any) that corresponds to a given official name:

```
>>> import unicodedata
>>> unicodedata.name('⚀')
'DIE FACE-1'
>>> unicodedata.name('Ⅵ')
'ROMAN NUMERAL SIX'
>>> int('Ⅵ')
ValueError: invalid literal for int() with base 10: 'Ⅵ'
>>> unicodedata.numeric('Ⅵ')  # use unicodedata to get numeric value
6.0
>>> unicodedata.lookup('RECYCLING SYMBOL FOR TYPE-1 PLASTICS')
'♳'
```

Strings and Things



10
Regular Expressions

Regular expressions (REs, aka regexps) let programmers specify pattern strings and perform searches and substitutions. Regular expressions are not easy to master, but they can be a powerful tool for processing text. Python offers rich regular expression functionality through the built-in `re` module. In this chapter, we thoroughly present all about Python's REs.

Regular Expressions and the re Module

A regular expression is built from a string that represents a pattern. With RE functionality, you can examine any string and check which parts of the string, if any, match the pattern.

The `re` module supplies Python's RE functionality. The `compile` function builds an RE object from a pattern string and optional flags. The methods of an RE object look for matches of the RE in a string or perform substitutions. The `re` module also exposes functions equivalent to an RE object's methods, but with the RE's pattern string as the first argument.

This chapter covers the use of REs in Python; it does not teach every minute detail about how to create RE patterns. For general coverage of REs, we recommend the book *Mastering Regular Expressions*, by Jeffrey Friedl (O'Reilly), offering thorough coverage of REs at both tutorial and advanced levels. Many tutorials and references on REs can also be found online, including an excellent, detailed tutorial in Python's online docs. Sites like Pythex and regex101 let you test your REs interactively. Alternatively, you can start IDLE, the Python REPL, or any other interactive interpreter, **`import`** `re`, and experiment directly.

REs and bytes Versus str

REs in Python work in two ways, depending on the type of the object being matched: when applied to `str` instances, an RE matches accordingly (e.g., a Unicode character *c* is deemed to be "a letter" if `'LETTER' in unicodedata.name(c)`); when applied to `bytes` instances, an RE matches in terms of ASCII (e.g., a byte *c* is deemed to be "a letter" if `c in string.ascii_letters`). For example:

```
import re
print(re.findall(r'\w+', 'cittá'))            # prints: ['cittá']
print(re.findall(rb'\w+', 'cittá'.encode()))  # prints: [b'citt']
```

Pattern String Syntax

The pattern string representing a regular expression follows a specific syntax:

- Alphabetic and numeric characters stand for themselves. An RE whose pattern is a string of letters and digits matches the same string.
- Many alphanumeric characters acquire special meaning in a pattern when they are preceded by a backslash (\), or *escaped*.
- Punctuation characters work the other way around: they stand for themselves when escaped but have special meaning when unescaped.
- The backslash character is matched by a repeated backslash (\\).

An RE pattern is a string concatenating one or more pattern elements; each element in turn is itself an RE pattern. For example, `r'a'` is a one-element RE pattern that matches the letter `a`, and `r'ax'` is a two-element RE pattern that matches an `a` immediately followed by an `x`.

Since RE patterns often contain backslashes, it's best to always specify RE patterns in raw string literal form (covered in "Strings" on page 44). Pattern elements (such as `r'\t'`, equivalent to the string literal `'\\t'`) do match the corresponding special characters (in this case, the tab character `\t`), so you can use a raw string literal even when you need a literal match for such special characters.

Table 10-1 lists the special elements in RE pattern syntax. The exact meanings of some pattern elements change when you use optional flags, together with the pattern string, to build the RE object. The optional flags are covered in "Optional Flags" on page 311.

Table 10-1. RE pattern syntax

Element	Meaning
`.`	Matches any single character except `\n` (if `DOTALL`, also matches `\n`)
`^`	Matches start of string (if `MULTILINE`, also matches right after `\n`)
`$`	Matches end of string (if `MULTILINE`, also matches right before `\n`)
`*`	Matches zero or more cases of the previous RE; greedy (matches as many as possible)

Element	Meaning
+	Matches one or more cases of the previous RE; greedy (matches as many as possible)
?	Matches zero or one cases of the previous RE; greedy (matches one if possible)
*?, +?, ??	Nongreedy versions of *, +, and ?, respectively (match as few as possible)
{*m*}	Matches *m* cases of the previous RE
{*m*, *n*}	Matches between *m* and *n* cases of the previous RE; *m* or *n* (or both) may be omitted, defaulting to *m*=0 and *n*=infinity (greedy)
{*m*, *n*}?	Matches between *m* and *n* cases of the previous RE (nongreedy)
[...]	Matches any one of a set of characters contained within the brackets
[^...]	Matches one character *not* contained within the brackets after the caret ^
|	Matches either the preceding RE or the following RE
(...)	Matches the RE within the parentheses and indicates a *group*
(?aiLmsux)	Alternate way to set optional flags[a]
(?:...)	Like (...) but does not capture the matched characters in a group
(?P<*id*>...)	Like (...) but the group also gets the name <*id*>
(?P=<*id*>)	Matches whatever was previously matched by the group named <*id*>
(?#...)	Content of parentheses is just a comment; no effect on match
(?=...)	*Lookahead assertion*: matches if RE ... matches what comes next, but does not consume any part of the string
(?!...)	*Negative lookahead assertion*: matches if RE ... does *not* match what comes next, and does not consume any part of the string
(?<=...)	*Lookbehind assertion*: matches if there is a match ending at the current position for RE ... (... must match a fixed length)
(?<!...)	*Negative lookbehind assertion*: matches if there is no match ending at the current position for RE ... (... must match a fixed length)
\ *number*	Matches whatever was previously matched by the group numbered *number* (groups are automatically numbered left to right, from 1 to 99)
\A	Matches an empty string, but only at the start of the whole string
\b	Matches an empty string, but only at the start or end of a *word* (a maximal sequence of alphanumeric characters; see also \w)
\B	Matches an empty string, but not at the start or end of a word
\d	Matches one digit, like the set [0-9] (in Unicode mode, many other Unicode characters also count as "digits" for \d, but not for [0-9])
\D	Matches one nondigit character, like the set [^0-9] (in Unicode mode, many other Unicode characters also count as "digits" for \D, but not for [^0-9])
\N{*name*}	**3.8+** Matches the Unicode character corresponding to *name*
\s	Matches a whitespace character, like the set [\t\n\r\f\v]
\S	Matches a nonwhitespace character, like the set [^\t\n\r\f\v]

Element	Meaning
`\w`	Matches one alphanumeric character; unless in Unicode mode, or if `LOCALE` or `UNICODE` is set, `\w` is like `[a-zA-Z0-9_]`
`\W`	Matches one nonalphanumeric character, the reverse of `\w`
`\Z`	Matches an empty string, but only at the end of the whole string
`\\`	Matches one backslash character

[a] Always place the `(?...)` construct for setting flags, if any, at the start of the pattern, for readability; placing it elsewhere raises `DeprecationWarning`.

Using a `\` character followed by an alphabetic character not listed here or in Table 3-4 raises an `re.error` exception.

Common Regular Expression Idioms

Always Use r'...' Syntax for RE Pattern Literals

Use raw string literals for all RE pattern literals, and only for them. This ensures you'll never forget to escape a backslash (`\`), and improves code readability since it makes your RE pattern literals stand out.

`.*` as a substring of a regular expression's pattern string means "any number of repetitions (zero or more) of any character." In other words, `.*` matches any substring of a target string, including the empty substring. `.+` is similar but matches only a nonempty substring. For example, this:

```
r'pre.*post'
```

matches a string containing a substring `'pre'` followed by a later substring `'post'`, even if the latter is adjacent to the former (e.g., it matches both `'prepost'` and `'pre23post'`). On the other hand, this:

```
r'pre.+post'
```

matches only if `'pre'` and `'post'` are not adjacent (e.g., it matches `'pre23post'` but does not match `'prepost'`). Both patterns also match strings that continue after the `'post'`. To constrain a pattern to match only strings that *end* with `'post'`, end the pattern with `\Z`. For example, this:

```
r'pre.*post\Z'
```

matches `'prepost'` but not `'preposterous'`.

All of these examples are *greedy*, meaning that they match the substring beginning with the first occurrence of `'pre'` all the way to the *last* occurrence of `'post'`. When you care about what part of the string you match, you may often want to specify *nongreedy* matching, which in our example would match the substring beginning with the first occurrence of `'pre'` but only up to the *first* following occurrence of `'post'`.

For example, when the string is `'preposterous and post facto'`, the greedy RE pattern `r'pre.*post'` matches the substring `'preposterous and post'`; the nongreedy variant `r'pre.*?post'` matches just the substring `'prepost'`.

Another frequently used element in RE patterns is `\b`, which matches a word boundary. To match the word `'his'` only as a whole word and not its occurrences as a substring in such words as `'this'` and `'history'`, the RE pattern is:

```
r'\bhis\b'
```

with word boundaries both before and after. To match the beginning of any word starting with `'her'`, such as `'her'` itself and `'hermetic'`, but not words that just contain `'her'` elsewhere, such as `'ether'` or `'there'`, use:

```
r'\bher'
```

with a word boundary before, but not after, the relevant string. To match the end of any word ending with `'its'`, such as `'its'` itself and `'fits'`, but not words that contain `'its'` elsewhere, such as `'itsy'` or `'jujitsu'`, use:

```
r'its\b'
```

with a word boundary after, but not before, the relevant string. To match whole words thus constrained, rather than just their beginning or end, add a pattern element `\w*` to match zero or more word characters. To match any full word starting with `'her'`, use:

```
r'\bher\w*'
```

To match just the first three letters of any word starting with `'her'`, but not the word `'her'` itself, use a negative word boundary `\B`:

```
r'\bher\B'
```

To match any full word ending with `'its'`, including `'its'` itself, use:

```
r'\w*its\b'
```

Sets of Characters

You denote sets of characters in a pattern by listing the characters within brackets (`[]`). In addition to listing characters, you can denote a range by giving the first and last characters of the range separated by a hyphen (`-`). The last character of the range is included in the set, differently from other Python ranges. Within a set, special characters stand for themselves, except `\`, `]`, and `-`, which you must escape (by preceding them with a backslash) when their position is such that, if not escaped, they would form part of the set's syntax. You can denote a class of characters within a set by escaped-letter notation, such as `\d` or `\S`. `\b` in a set means a backspace character (`chr(8)`), not a word boundary. If the first character in the set's pattern, right after the `[`, is a caret (`^`), the set is *complemented*: such a set matches any character *except* those that follow `^` in the set pattern notation.

A frequent use of character sets is to match a "word," using a definition of which characters can make up a word that differs from `\w`'s default (letters and digits). To match a word of one or more characters, each of which can be an ASCII letter, an apostrophe, or a hyphen, but not a digit (e.g., `"Finnegan-O'Hara"`), use:

```
r"[a-zA-Z'\-]+"
```

Always Escape Hyphens in Character Sets

It's not strictly necessary to escape the hyphen with a backslash in this case, since its position at the end of the set makes the situation syntactically unambiguous. However, using the backslash is advisable because it makes the pattern more readable, by visually distinguishing the hyphen that you want to have as a character in the set from those used to denote ranges. (When you want to include a backslash in the character set, of course, you denote that by escaping the backslash itself: write it as `\\`.)

Alternatives

A vertical bar (`|`) in a regular expression pattern, used to specify alternatives, has low syntactic precedence. Unless parentheses change the grouping, `|` applies to the whole pattern on either side, up to the start or end of the pattern, or to another `|`. A pattern can be made up of any number of subpatterns joined by `|`. It is important to note that an RE of subpatterns joined by `|` will match the *first* matching subpattern, not the longest. A pattern like `r'ab|abc'` will never match `'abc'` because the `'ab'` match gets evaluated first.

Given a list *`L`* of words, an RE pattern that matches any one of the words is:

```
'|'.join(rf'\b{word}\b' for word in L)
```

Escaping Strings

If the items of *`L`* can be more general strings, not just words, you need to *escape* each of them with the function `re.escape` (covered in Table 10-6), and you may not want the `\b` word boundary markers on either side. In this case, you could use the following RE pattern (sorting the list in reverse order by length to avoid accidentally "masking" a longer word by a shorter one):

```
'|'.join(re.escape(s) for s in sorted(
         L, key=len, reverse=True))
```

Groups

A regular expression can contain any number of *groups*, from none to 99 (or even more, but only the first 99 groups are fully supported). Parentheses in a pattern string indicate a group. The element `(?P<id>...)` also indicates a group and gives the group a name, *id*, that can be any Python identifier. All groups, named and unnamed, are numbered, left to right, 1 to 99; "group 0" means the string that the whole RE matches.

For any match of the RE with a string, each group matches a substring (possibly an empty one). When the RE uses `|`, some groups may not match any substring, although the RE as a whole does match the string. When a group doesn't match any substring, we say that the group does not *participate* in the match. An empty string (`''`) is used as the matching substring for any group that does not participate in a match, except where otherwise indicated later in this chapter. For example, this:

```
r'(.+)\1+\Z'
```

matches a string made up of two or more repetitions of any nonempty substring. The `(.+)` part of the pattern matches any nonempty substring (any character, one or more times) and defines a group, thanks to the parentheses. The `\1+` part of the pattern matches one or more repetitions of the group, and `\Z` anchors the match to the end of the string.

Optional Flags

The optional `flags` argument to the function `compile` is a coded integer built by bitwise ORing (with Python's bitwise OR operator, `|`) one or more of the following attributes of the module `re`. Each attribute has both a short name (one uppercase letter), for convenience, and a long name (an uppercase multiletter identifier), which is more readable and thus normally preferable:

`A` *or* `ASCII`
: Uses ASCII-only characters for `\w`, `\W`, `\b`, `\B`, `\d`, and `\D`; overrides the default `UNICODE` flag

`I` *or* `IGNORECASE`
: Makes matching case-insensitive

`L` *or* `LOCALE`
: Uses the Python `LOCALE` setting to determine characters for `\w`, `\W`, `\b`, `\B`, `\d`, and `\D` markers; you can only use this option with `bytes` patterns

`M` *or* `MULTILINE`
: Makes the special characters `^` and `$` match at the start and end of each line (i.e., right after/before a newline), as well as at the start and end of the whole string (`\A` and `\Z` always match only the start and end of the whole string)

`S` *or* `DOTALL`
: Causes the special character `.` to match any character, including a newline

`U` *or* `UNICODE`
: Uses full Unicode to determine characters for `\w`, `\W`, `\b`, `\B`, `\d`, and `\D` markers; although retained for backward compatibility, this flag is now the default

`X` *or* `VERBOSE`
: Causes whitespace in the pattern to be ignored, except when escaped or in a character set, and makes a nonescaped `#` character in the pattern begin a comment that lasts until the end of the line

Flags can also be specified by inserting a pattern element with one or more of the letters `aiLmsux` between `(?` and `)`, rather than by the `flags` argument to the `compile` function of the `re` module (the letters correspond to the uppercase flags given in the preceding list). Options should always be placed at the start of the pattern; not doing this produces a deprecation warning. In particular, placement at the start is mandatory if `x` (the inline flag character for verbose RE parsing) is among the options, since `x` changes the way Python parses the pattern. Options apply to the whole RE, except that the `aLu` options can be applied locally within a group.

Using the explicit `flags` argument is more readable than placing an options element within the pattern. For example, here are three ways to define equivalent REs with the `compile` function. Each of these REs matches the word "hello" in any mix of upper- and lowercase letters:

```
import re
r1 = re.compile(r'(?i)hello')
r2 = re.compile(r'hello', re.I)
r3 = re.compile(r'hello', re.IGNORECASE)
```

The third approach is clearly the most readable, and thus the most maintainable, though slightly more verbose. The raw string form is not strictly necessary here, since the patterns do not include backslashes. However, using raw string literals does no harm, and we recommend you always use them for RE patterns to improve clarity and readability.

The option `re.VERBOSE` (or `re.X`) lets you make patterns more readable and understandable through appropriate use of whitespace and comments. Complicated and verbose RE patterns are generally best represented by strings that take up more than one line, and therefore you normally want to use a triple-quoted raw string literal for such pattern strings. For example, to match a string representing an integer that may be in octal, hex, or decimal format, you could use use either of the following:

```
repat_num1 = r'(0o[0-7]*|0x[\da-fA-F]+|[1-9]\d*)\Z'
repat_num2 = r'''(?x)   # (re.VERBOSE) pattern matching int literals
              (  0o [0-7]*       # octal: leading 0o, 0+ octal digits
               | 0x [\da-fA-F]+  # hex: 0x, then 1+ hex digits
               | [1-9] \d*       # decimal: leading non-0, 0+ digits
```

```
                    )\Z                 # end of string
                    '''
```

The two patterns defined in this example are equivalent, but the second one is made more readable and understandable by the comments and the free use of whitespace to visually group portions of the pattern in logical ways.

Match Versus Search

So far, we've been using regular expressions to *match* strings. For example, the RE with pattern `r'box'` matches strings such as `'box'` and `'boxes'`, but not `'inbox'`. In other words, an RE *match* is implicitly anchored at the start of the target string, as if the RE's pattern started with `\A`.

Often you'll be interested in locating possible matches for an RE anywhere in the string, without anchoring (e.g., find the `r'box'` match within such strings as `'inbox'`, as well as in `'box'` and `'boxes'`). In this case, the Python term for the operation is a *search*, as opposed to a match. For such searches, use the `search` method of an RE object instead of the `match` method, which matches only from the beginning of the string. For example:

```
import re
r1 = re.compile(r'box')
if r1.match('inbox'):
    print('match succeeds')
else:
    print('match fails')          # prints: match fails

if r1.search('inbox'):
    print('search succeeds')      # prints: search succeeds
else:
    print('search fails')
```

If you want to check that the *whole* string matches, not just its beginning, you can instead use the method `fullmatch`. All of these methods are covered in Table 10-3.

Anchoring at String Start and End

`\A` and `\Z` are the pattern elements ensuring that a regular expression match is *anchored* at the string's start or end. The elements `^` for start and `$` for end are also used in similar roles. For RE objects that are not flagged as `MULTILINE`, `^` is the same as `\A`, and `$` is the same as `\Z`. For a multiline RE, however, `^` can anchor at the start of the string *or* the start of any line (where "lines" are determined based on `\n` separator characters). Similarly, with a multiline RE, `$` can anchor at the end of the string *or* the end of any line. `\A` and `\Z` always anchor exclusively at the start and end of the string, whether the RE object is multiline or not.

For example, here's a way to check whether a file has any lines that end with digits:

```
import re
digatend = re.compile(r'\d$', re.MULTILINE)
with open('afile.txt') as f:
    if digatend.search(f.read()):
        print('some lines end with digits')
    else:
        print('no line ends with digits')
```

A pattern of `r'\d\n'` is almost equivalent, but in that case, the search fails if the very last character of the file is a digit not followed by an end-of-line character. With the preceding example, the search succeeds if a digit is at the very end of the file's contents, as well as in the more usual case where a digit is followed by an end-of-line character.

Regular Expression Objects

Table 10-2 covers the read-only attributes of a regular expression object *r* that detail how *r* was built (by the function `compile` of the module `re`, covered in Table 10-6).

Table 10-2. Attributes of RE objects

`flags`	The `flags` argument passed to `compile`, or `re.UNICODE` when `flags` is omitted; also includes any flags specified in the pattern itself using a leading `(?...)` element
`groupindex`	A dictionary whose keys are group names as defined by elements `(?P<id>...)`; the corresponding values are the named groups' numbers
`pattern`	The pattern string from which *r* is compiled

These attributes make it easy to retrieve from a compiled RE object its original pattern string and flags, so you never have to store those separately.

An RE object *r* also supplies methods to find matches for *r* in a string, as well as to perform substitutions on such matches (see Table 10-3). Matches are represented by special objects, covered in the following section.

Table 10-3. Methods of RE objects

`findall`	`r.findall(s)`
	`When r has no groups,` `findall` returns a list of strings, each a substring of *s* that is a nonoverlapping match with *r*. For example, to print out all words in a file, one per line:
	`import re`
	`reword = re.compile(r'\w+')`
	`with open('afile.txt') as f:`
	`    for aword in reword.findall(f.read()):`
	`        print(aword)`

`findall` *(cont.)*	When *r* has exactly one group, `findall` also returns a list of strings, but each is the substring of *s* that matches *r*'s group. For example, to print only words that are followed by whitespace (not words followed by punctuation or the word at end of the string), you need to change only one statement in the preceding example:
	`reword = re.compile('(\w+)\s')`
	When *r* has *n* `groups` (with *n* > 1), `findall` returns a list of tuples, one per nonoverlapping match with *r*. Each tuple has *n* items, one per group of *r*, the substring of *s* matching the group. For example, to print the first and last word of each line that has at least two words:
	`import re`
	`first_last = re.compile(r'^\W*(\w+)\b.*\b(\w+)\W*$',`
	`                        re.MULTILINE)`
	`with open('afile.txt') as f:`
	`    for first, last in first_last.findall(f.read()):`
	`        print(first, last)`

`finditer`	`r.finditer(s)` `finditer` is like `findall`, except that, instead of a list of strings or tuples, it returns an iterator whose items are match objects (discussed in the following section). In most cases, therefore, `finditer` is more flexible, and usually performs better, than `findall`.
`fullmatch`	`r.fullmatch(s, start=0, end=sys.maxsize)` Returns a match object when the complete substring *s*, starting at index `start` and ending just short of index end, matches *r*. Otherwise, `fullmatch` returns **None**.

`match`	`r.match(s, start=0, end=sys.maxsize)`
	Returns an appropriate match object when a substring of *s*, starting at index `start` and not reaching as far as index end, matches *r*. Otherwise, `match` returns **None**. `match` is implicitly anchored at the starting position `start` in *s*. To search for a match with *r* at any point in *s* from `start` onward, call `r.search`, not `r.match`. For example, here is one way to print all lines in a file that start with digits:
	`import re`
	`digs = re.compile(r'\d')`
	`with open('afile.txt') as f:`
	`    for line in f:`
	`        if digs.match(line):`
	`            print(line, end='')`

`search`	`r.search(s, start=0, end=sys.maxsize)`
	Returns an appropriate match object for the leftmost substring of *s*, starting not before index `start` and not reaching as far as index end, that matches *r*. When no such substring exists, `search` returns **None**. For example, to print all lines containing digits, one simple approach is as follows:
	`import re`
	`digs = re.compile(r'\d')`
	`with open('afile.txt') as f:`
	`    for line in f:`
	`        if digs.search(line):`
	`            print(line, end='')`

split	`r.split(s, maxsplit=0)`

Returns a list *L* of the *splits* of *s* by *r* (i.e., the substrings of *s* separated by nonoverlapping, nonempty matches with *r*). For example, here's a way to eliminate all occurrences of `'hello'` (in any mix of lowercase and uppercase) from a string:

```
import re
rehello = re.compile(r'hello', re.IGNORECASE)
astring = ''.join(rehello.split(astring))
```

When *r* has *n* groups, *n* more items are interleaved in *L* between each pair of splits. Each of the *n* extra items is the substring of *s* that matches *r*'s corresponding group in that match, or **None** if that group did not participate in the match. For example, here's one way to remove whitespace only when it occurs between a colon and a digit:

```
import re
re_col_ws_dig = re.compile(r'(:)\s+(\d)')
astring = ''.join(re_col_ws_dig.split(astring))
```

If `maxsplit` is greater than `0`, at most `maxsplit` splits are in *L*, each followed by *n* items, while the trailing substring of *s* after `maxsplit` matches of *r*, if any, is *L*'s last item. For example, to remove only the *first* occurrence of substring `'hello'` rather than *all* of them, change the last statement in the first example here to:

```
astring=''.join(rehello.split(astring, 1))
```

sub	`r.sub(repl, s, count=0)`

Returns a copy of *s* where nonoverlapping matches with *r* are replaced by *repl*, which can be either a string or a callable object, such as a function. An empty match is replaced only when not adjacent to the previous match. When `count` is greater than `0`, only the first `count` matches of *r* within *s* are replaced. When `count` equals `0`, all matches of *r* within *s* are replaced. For example, here's another, more natural way to remove only the first occurrence of substring `'hello'` in any mix of cases:

```
import re
rehello = re.compile(r'hello', re.IGNORECASE)
astring = rehello.sub('', astring, 1)
```

Without the final `1` (one) argument to `sub`, the example removes all occurrences of `'hello'`.

When *repl* is a callable object, *repl* must accept one argument (a match object) and return a string (or **None**, which is equivalent to returning the empty string `''`) to use as the replacement for the match. In this case, `sub` calls *repl*, with a suitable match object argument, for each match with *r* that `sub` is replacing. For example, here's one way to uppercase all occurrences of words starting with `'h'` and ending with `'o'` in any mix of cases:

```
import re
h_word = re.compile(r'\bh\w*o\b', re.IGNORECASE)
def up(mo):
    return mo.group(0).upper()
astring = h_word.sub(up, astring)
```

sub *(cont.)*	When *repl* is a string, sub uses *repl* itself as the replacement, except that it expands backreferences. A *backreference* is a substring of *repl* of the form \g<*id*>, where *id* is the name of a group in *r* (established by the syntax (?P<*id*>...) in *r*'s pattern string) or \dd, where *dd* is one or two digits taken as a group number. Each back reference, named or numbered, is replaced with the substring of *s* that matches the group of *r* that the back reference indicates. For example, here's a way to enclose every word in braces:
	`import re`
	`grouped_word = re.compile('(\w+)')`
	`astring = grouped_word.sub(r'{\1}', astring)`

subn	*r*.subn(*repl*, *s*, count=0)
	subn is the same as sub, except that subn returns a pair (*new_string*, *n*), where *n* is the number of substitutions that subn has performed. For example, here's one way to count the number of occurrences of substring 'hello' in any mix of cases:
	`import re`
	`rehello = re.compile(r'hello', re.IGNORECASE)`
	`_, count = rehello.subn('', astring)`
	`print(f'Found {count} occurrences of "hello"')`

Match Objects

Match objects are created and returned by the methods fullmatch, match, and search of a regular expression object, and are the items of the iterator returned by the method finditer. They are also implicitly created by the methods sub and subn when the argument *repl* is callable, since in that case the appropriate match object is passed as the only argument on each call to *repl*. A match object *m* supplies the following read-only attributes that detail how search or match created *m*, listed in Table 10-4.

Table 10-4. Attributes of match objects

pos	The *start* argument that was passed to search or match (i.e., the index into *s* where the search for a match began)
endpos	The *end* argument that was passed to search or match (i.e., the index into *s* before which the matching substring of *s* had to end)
lastgroup	The name of the last-matched group (**None** if the last-matched group has no name, or if no group participated in the match)
lastindex	The integer index (1 and up) of the last-matched group (**None** if no group participated in the match)
re	The RE object *r* whose method created *m*
string	The string *s* passed to finditer, fullmatch, match, search, sub, or subn

In addition, match objects supply the methods detailed in Table 10-5.

Table 10-5. Methods of match objects

`end`, `span`, `start`	`m.end(groupid=0)`, `m.span(groupid=0)`, `m.start(groupid=0)` These methods return indices within `m.string` of the substring that matches the group identified by *`groupid`* (a group number or name; `0`, the default value for `groupid`, means "the whole RE"). When the matching substring is `m.string[i:j]`, `m.start` returns *`i`*, `m.end` returns *`j`*, and `m.span` returns `(i, j)`. If the group did not participate in the match, *`i`* and *`j`* are `-1`.
`expand`	`m.expand(s)` Returns a copy of *`s`* where escape sequences and backreferences are replaced in the same way as for the method `r.sub`, covered in Table 10-3.
`group`	`m.group(groupid=0, *groupids)` Called with a single argument `groupid` (a group number or name), `m.group` returns the substring matching the group identified by `groupid`, or **None** when that group did not participate in the match. `m.group()`—or `m.group(0)`—returns the whole matched substring (group `0` means the whole RE). Groups can also be accessed using `m[index]` notation, as if called using `m.group(index)` (in either case, *`index`* may be an `int` or a `str`). When `group` is called with multiple arguments, each argument must be a group number or name. `group` then returns a tuple with one item per argument, the substring matching the corresponding group, or **None** when that group did not participate in the match.
`groupdict`	`m.groupdict(default=None)` Returns a dictionary whose keys are the names of all named groups in *`r`*. The value for each name is the substring that matches the corresponding group, or `default` if that group did not participate in the match.
`groups`	`m.groups(default=None)` Returns a tuple with one item per group in *`r`*. Each item is the substring matching the corresponding group, or `default` if that group did not participate in the match. The tuple does not include the `0` group representing the full pattern match.

Functions of the re Module

In addition to the attributes listed in "Optional Flags" on page 311, the `re` module provides one function for each method of a regular expression object (`findall`, `finditer`, `fullmatch`, `match`, `search`, `split`, `sub`, and `subn`, described in Table 10-3), each with an additional first argument, a pattern string that the function implicitly compiles into an RE object. It is usually better to compile pattern strings into RE objects explicitly and call the RE object's methods, but sometimes, for a one-off use of an RE pattern, calling functions of the module `re` can be handier. For example, to count the number of occurrences of `'hello'` in any mix of cases, one concise, function-based way is:

```
import re
_, count = re.subn(r'hello', '', astring, flags=re.I)
print(f'Found {count} occurrences of "hello"')
```

The `re` module internally caches RE objects it creates from the patterns passed to functions; to purge the cache and reclaim some memory, call `re.purge`.

The `re` module also supplies `error`, the class of exceptions raised upon errors (generally, errors in the syntax of a pattern string), and two more functions, listed in Table 10-6.

Table 10-6. Additional `re` functions

`compile`	`compile(`*`pattern`*`, flags=0)` Creates and returns an RE object, parsing the string *`pattern`*, as per the syntax covered in "Pattern String Syntax" on page 306, and using integer `flags`, as described in "Optional Flags" on page 311
`escape`	`escape(`*`s`*`)` Returns a copy of string *`s`* with each nonalphanumeric character escaped (i.e., preceded by a backslash, \); useful to match string *`s`* literally as part of an RE pattern string

REs and the := Operator

The introduction of the `:=` operator in Python 3.8 established support for a successive-match idiom in Python similar to the one that's common in Perl. In this idiom, a series of **`if/elsif`** branches tests a string against different regular expressions. In Perl, the **`if`** `($var =~ /regExpr/)` statement both evaluates the regular expression and saves the successful match in the variable `var`:[1]

```
if    ($statement =~ /I love (\w+)/) {
  print "He loves $1\n";
}
elsif ($statement =~ /Ich liebe (\w+)/) {
  print "Er liebt $1\n";
}
elsif ($statement =~ /Je t\'aime (\w+)/) {
  print "Il aime $1\n";
}
```

Prior to Python 3.8, this evaluate-and-store behavior was not possible in a single **`if/elif`** statement; developers had to use a cumbersome cascade of nested **`if/else`** statements:

```
m = re.match('I love (\w+)', statement)
if m:
    print(f'He loves {m.group(1)}')
else:
```

1 This example is taken from regex; see "Match groups in Python" on Stack Overflow.

```
    m = re.match('Ich liebe (\w+)', statement)
    if m:
        print(f'Er liebt {m.group(1)}')
    else:
         m = re.match('J'aime (\w+)', statement)
        if m:
            print(f'Il aime {m.group(1)}')
```

Using the := operator, this code simplifies to:

```
if m := re.match(r'I love (\w+)', statement):
    print(f'He loves {m.group(1)}')

elif m := re.match(r'Ich liebe (\w+)', statement):
    print(f'Er liebt {m.group(1)}')

elif m := re.match(r'J'aime (\w+)', statement):
    print(f'Il aime {m.group(1)}')
```

The Third-Party regex Module

As an alternative to the Python standard library's `re` module, a popular package for regular expressions is the third-party `regex` module, by Matthew Barnett. `regex` has an API that's compatible with the `re` module and adds a number of extended features, including:

- Recursive expressions
- Defining character sets by Unicode property/value
- Overlapping matches
- Fuzzy matching
- Multithreading support (releases GIL during matching)
- Matching timeout
- Unicode case folding in case-insensitive matches
- Nested sets

11
File and Text Operations

This chapter covers issues related to files and filesystems in Python. A *file* is a stream of text or bytes that a program can read and/or write; a *filesystem* is a hierarchical repository of files on a computer system.

> **Other Chapters That Also Deal with Files**
>
> Files are a crucial concept in programming: so, although this chapter is one of the largest in the book, other chapters also have material relevant to handling specific kinds of files. In particular, Chapter 12 deals with many kinds of files related to persistence and database functionality (CSV files in Chapter 12, JSON files in "The json Module" on page 386, pickle files in "The pickle Module" on page 389, shelve files in "The shelve Module" on page 395, DBM and DBM-like files in "The dbm Package" on page 397, and SQLite database files in "SQLite" on page 405), Chapter 22 deals with files in HTML format, and Chapter 23 deals with files in XML format.

Files and streams come in many flavors. Their contents can be arbitrary bytes, or text. They may be suitable for reading, writing, or both, and they may be *buffered*, so that data is temporarily held in memory on the way to or from the file. Files may also allow *random access*, moving forward and back within the file, or jumping to read or write at a particular location in the file. This chapter covers each of these topics.

In addition, this chapter also covers the polymorphic concept of file-like objects (objects that are not actually files but behave to some extent like files), modules that deal with temporary files and file-like objects, and modules that help you access the contents of text and binary files and support compressed files and other data archives. Python's standard library supports several kinds of lossless compression, including (ordered by the typical ratio of compression on a text file, from highest to lowest):

- LZMA (used, for example, by the `xz` program), see module `lzma`
- bzip2 (used, for example, by the `bzip2` program), see module `bz2`
- deflate (used, for example, by the `gzip` and `zip` programs), see modules `zlib`, `gzip`, and `zipfile`

The `tarfile` module lets you read and write TAR files compressed with any one of these algorithms. The `zipfile` module lets you read and write ZIP files and also handles bzip2 and LZMA compressions. We cover both of these modules in this chapter. We don't cover the details of compression in this book; for details, see the online docs.

In the rest of this chapter, we will refer to all files and file-like objects as files.

In modern Python, input/output (I/O) is handled by the standard library's `io` module. The `os` module supplies many of the functions that operate on the filesystem, so this chapter also introduces that module. It then covers operations on the filesystem (comparing, copying, and deleting directories and files; working with filepaths; and accessing low-level file descriptors) provided by the `os` module, the `os.path` module, and the new and preferable `pathlib` module, which provides an object-oriented approach to filesystem paths. For a cross-platform interprocess communication (IPC) mechanism known as *memory-mapped files*, see the module `mmap`, covered in Chapter 15.

While most modern programs rely on a graphical user interface (GUI), often via a browser or a smartphone app, text-based, nongraphical "command-line" user interfaces are still very popular for their ease, speed of use, and scriptability. This chapter concludes with a discussion of non-GUI text input and output in Python in "Text Input and Output" on page 368, terminal text I/O in "Richer-Text I/O" on page 371, and, finally, how to build software showing text understandable to different users, across languages and cultures, in "Internationalization" on page 374.

The io Module

As mentioned in this chapter's introduction, `io` is the standard library module in Python that provides the most common ways for your Python programs to read or write files. In modern Python, the built-in function `open` is an alias for the function `io.open`. Use `io.open` (or its built-in alias `open`) to make a Python file object to read from, and/or write to, a file as seen by the underlying operating system. The parameters you pass to open determine what type of object is returned. This object can be an instance of `io.TextIOWrapper` if textual, or, if binary, one of `io.BufferedReader`, `io.BufferedWriter`, or `io.BufferedRandom`, depending on whether it's read-only, write-only, or read/write. This section covers the various types of file objects, as well as the important issue of making and using *temporary* files (on disk, or even in memory).

I/O Errors Raise OSError

Python reacts to any I/O error related to a file object by raising an instance of built-in exception class `OSError` (many useful subclasses exist, as covered in "OSError subclasses" on page 208). Errors causing this exception include a failing `open` call, calls to a method on a file to which the method doesn't apply (e.g., `write` on a read-only file, or `seek` on a nonseekable file), and actual I/O errors diagnosed by a file object's methods.

The `io` module also provides the underlying classes, both abstract and concrete, that, by inheritance and by composition (also known as *wrapping*), make up the file objects that your program generally uses. We do not cover these advanced topics in this book. If you have access to unusual channels for data, or nonfilesystem data storage, and want to provide a file interface to those channels or storage, you can ease your task (through appropriate subclassing and wrapping) using other classes in the `io` module. For assistance with such advanced tasks, consult the online docs.

Creating a File Object with open

To create a Python file object, call `open` with the following syntax:

```
open(file, mode='r', buffering=-1, encoding=None, errors='strict',
     newline=None, closefd=True, opener=os.open)
```

`file` can be a string or an instance of `pathlib.Path` (any path to a file as seen by the underlying OS), or an `int` (an OS-level *file descriptor* as returned by `os.open`, or by whatever function you pass as the `opener` argument). When `file` is a path (a string or `pathlib.Path` instance), `open` opens the file thus named (possibly creating it, depending on the `mode` argument—despite its name, `open` is not just for opening existing files: it can also create new ones). When `file` is an integer, the underlying OS file must already be open (via `os.open`).

Opening a File Pythonically

`open` is a context manager: use **`with`** `open(...)` **`as`** *`f`*:, *not* *f* = `open(...)`, to ensure the file *`f`* gets closed as soon as the **`with`** statement's body is done.

`open` creates and returns an instance *`f`* of the appropriate `io` module class, depending on the mode and buffering settings. We refer to all such instances as file objects; they are polymorphic with respect to each other.

mode

`mode` is an optional string indicating how the file is to be opened (or created). The possible values for `mode` are listed in Table 11-1.

Table 11-1. `mode` settings

Mode	Meaning
`'a'`	The file is opened in write-only mode. The file is kept intact if it already exists, and the data you write is appended to the existing contents. The file is created if it does not exist. Calling *`f`*`.seek` on the file changes the result of the method *`f`*`.tell`, but does not change the write position in the file opened in this `mode`: that write position always remains at the end of the file.
`'a+'`	The file is opened for both reading and writing, so all methods of *f* can be called. The file is kept intact if it already exists, and the data you write is appended to the existing contents. The file is created if it does not exist. Calling *`f`*`.seek` on the file, depending on the underlying operating system, may have no effect when the next I/O operation on *f writes* data, but does work normally when the next I/O operation on *f reads* data.
`'r'`	The file must already exist, and it is opened in read-only mode (this is the default).
`'r+'`	The file must exist and is opened for both reading and writing, so all methods of *f* can be called.
`'w'`	The file is opened in write-only mode. The file is truncated to zero length and overwritten if it already exists, or created if it does not exist.
`'w+'`	The file is opened for both reading and writing, so all methods of *f* can be called. The file is truncated to zero length and overwritten if it already exists, or created if it does not exist.

Binary and text modes

The `mode` string may include any of the values in Table 11-1, followed by a `b` or `t`. `b` indicates that the file should be opened (or created) in binary mode, while `t` indicates text mode. When neither `b` nor `t` is included, the default is text (i.e., `'r'` is like `'rt'`, `'w+'` is like `'w+t'`, and so on), but per The Zen of Python, "explicit is better than implicit."

Binary files let you read and/or write strings of type `bytes`, and text files let you read and/or write Unicode text strings of type `str`. For text files, when the underlying channel or storage system deals in bytes (as most do), `encoding` (the name of an encoding known to Python) and `errors` (an error-handler name such as `'strict'`, `'replace'`, and so on, as covered under `decode` in Table 9-1) matter, as they specify how to translate between text and bytes, and what to do on encoding and decoding errors.

Buffering

`buffering` is an integer value that denotes the buffering policy you're requesting for the file. When `buffering` is `0`, the file (which must be binary mode) is unbuffered; the effect is as if the file's buffer is flushed every time you write anything to the file. When `buffering` is `1`, the file (which *must* be open in text mode) is line buffered, which means the file's buffer is flushed every time you write `\n` to the file. When `buffering` is greater than `1`, the file uses a buffer of about `buffering` bytes, often rounded up to some value convenient for the driver software. When `buffering` is `<0`, a default is used, depending on the type of file stream. Normally, this default is line buffering for files that correspond to interactive streams, and a buffer of `io.DEFAULT_BUFFER_SIZE` bytes for other files.

Sequential and nonsequential ("random") access

A file object *f* is inherently sequential (a stream of bytes or text). When you read, you get bytes or text in the sequential order in which they are present. When you write, the bytes or text you write are added in the order in which you write them.

For a file object *f* to support nonsequential access (also known as random access), it must keep track of its current position (the position in the storage where the next read or write operation starts transferring data), and the underlying storage for the file must support setting the current position. *f*`.seekable` returns **`True`** when *f* supports nonsequential access.

When you open a file, the default initial read/write position is at the start of the file. Opening *f* with a `mode` of `'a'` or `'a+'` sets *f*'s read/write position to the end of the file before writing data to *f*. When you write or read *n* bytes to/from file object *f*, *f*'s position advances by *n*. You can query the current position by calling *f*`.tell`, and change the position by calling *f*`.seek`, both covered in the next section.

When calling *f*`.seek` on a text-mode *f*, the offset you pass must be `0` (to position *f* at the start or end, depending on *f*`.seek`'s second parameter), or the opaque result returned by an earlier call to *f*`.tell`,[1] to position *f* back to a spot you had thus "bookmarked" before.

Attributes and Methods of File Objects

A file object *f* supplies the attributes and methods documented in Table 11-2.

Table 11-2. Attributes and methods of file objects

`close`	`close()` Closes the file. You can call no other method on *f* after *f*`.close`. Multiple calls to *f*`.close` are allowed and innocuous.
`closed`	*f*`.closed` is a read-only attribute that is **`True`** when *f*`.close()` has been called; otherwise, it is **`False`**.
`encoding`	*f*`.encoding` is a read-only attribute, a string naming the encoding (as covered in "Unicode" on page 301). The attribute does not exist on binary files.
`fileno`	`fileno()` Returns the file descriptor of *f*'s file at operating system level (an integer). File descriptors are covered in "File and directory functions of the os module" on page 345.

[1] `tell`'s value is opaque for text files, since they contain variable-length characters. For binary files, it's simply a straight byte count.

`flush`	`flush()` Requests that *f*'s buffer be written out to the operating system, so that the file as seen by the system has the exact contents that Python's code has written. Depending on the platform and the nature of *f*'s underlying file, `f.flush` may not be able to ensure the desired effect.
`isatty`	`isatty()` Returns **`True`** when *f*'s underlying file is an interactive stream, such as to or from a terminal; otherwise, returns **`False`**.
`mode`	`f.mode` is a read-only attribute that is the value of the `mode` string used in the `io.open` call that created *f*.
`name`	`f.name` is a read-only attribute that is the value of the file (`str` or `bytes`) or `int` used in the `io.open` call that created *f*. When `io.open` was called with a `pathlib.Path` instance *p*, `f.name` is `str(p)`.
`read`	`read(size=-1, /)` When *f* is open in binary mode, reads up to *`size`* bytes from *f*'s file and returns them as a bytestring. `read` reads and returns less than *`size`* bytes if the file ends before *`size`* bytes are read. When *`size`* is less than `0`, `read` reads and returns all bytes up to the end of the file. `read` returns an empty string when the file's current position is at the end of the file or when *`size`* equals `0`. When *f* is open in text mode, *`size`* is a number of characters, not bytes, and `read` returns a text string.
`readline`	`readline(size=-1, /)` Reads and returns one line from *f*'s file, up to the end of line (`\n`), included. When *`size`* is greater than or equal to `0`, reads no more than *`size`* bytes. In that case, the returned string might not end with `\n`. `\n` might also be absent when `readline` reads up to the end of the file without finding `\n`. `readline` returns an empty string when the file's current position is at the end of the file or when *`size`* equals `0`.
`readlines`	`readlines(size=-1, /)` Reads and returns a list of all lines in *f*'s file, each a string ending in `\n`. If *`size`* `> 0`, `readlines` stops and returns the list after collecting data for a total of about *`size`* bytes rather than reading all the way to the end of the file; in that case, the last string in the list might not end in `\n`.
`seek`	`seek(pos, how=io.SEEK_SET, /)` Sets *f*'s current position to the integer byte offset *`pos`* away from a reference point. *`how`* indicates the reference point. The `io` module has attributes named `SEEK_SET`, `SEEK_CUR`, and `SEEK_END`, to specify that the reference point is, respectively, the file's beginning, current position, or end. When *f* is opened in text mode, `f.seek` must have a *`pos`* of `0`, or, for `io.SEEK_SET` only, a *`pos`* that is the result of a previous call to `f.tell`. When *f* is opened in mode `'a'` or `'a+'`, on some but not all platforms, data written to *f* is appended to the data that is already in *f*, regardless of calls to `f.seek`.
`tell`	`tell()` Returns *f*'s current position: for a binary file this is an integer offset in bytes from the start of the file, and for a text file it's an opaque value usable in future calls to `f.seek` to position *f* back to the position that is now current.

truncate	`truncate(size=None, /)` Truncates *f*'s file, which must be open for writing. When `size` is present, truncates the file to be at most `size` bytes. When `size` is absent, uses `f.tell()` as the file's new size. `size` may be larger than the current file size; in this case, the resulting behavior is platform dependent.
write	`write(s, /)` Writes the bytes of string `s` (binary or text, depending on *f*'s mode) to the file.

writelines	`writelines(lst, /)`
	Like:
	`for line in lst: f.write(line)`
	It does not matter whether the strings in iterable *lst* are lines: despite its name, the method `writelines` just writes each of the strings to the file, one after the other. In particular, `writelines` does not add line-ending markers: such markers, if required, must already be present in the items of *lst*.

Iteration on File Objects

A file object *f*, open for reading, is also an iterator whose items are the file's lines. Thus, the loop:

```
for line in f:
```

iterates on each line of the file. Due to buffering issues, interrupting such a loop prematurely (e.g., with **break**), or calling `next(f)` instead of `f.readline()`, leaves the file's position set to an arbitrary value. If you want to switch from using *f* as an iterator to calling other reading methods on *f*, be sure to set the file's position to a known value by appropriately calling `f.seek`. On the plus side, a loop directly on *f* has very good performance, since these specifications allow the loop to use internal buffering to minimize I/O without taking up excessive amounts of memory even for huge files.

File-Like Objects and Polymorphism

An object *x* is file-like when it behaves *polymorphically* to a file object as returned by `io.open`, meaning that we can use *x* "as if" *x* were a file. Code using such an object (known as *client code* of the object) usually gets the object as an argument, or by calling a factory function that returns the object as the result. For example, if the only method that client code calls on *x* is `x.read`, without arguments, then all *x* needs to supply in order to be file-like enough for that code is a method `read` that is callable without arguments and returns a string. Other client code may need *x* to implement a larger subset of file methods. File-like objects and polymorphism are not absolute concepts: they are relative to demands placed on an object by some specific client code.

Polymorphism is a powerful aspect of object-oriented programming, and file-like objects are a good example of polymorphism. A client-code module that writes to or reads from files can automatically be reused for data residing elsewhere, as long as the module does not break polymorphism by type checking. When we discussed the built-ins `type` and `isinstance` in Table 8-1, we mentioned that type checking is often best avoided, as it blocks Python's normal polymorphism. Often, to support polymorphism in your client code, you just need to avoid type checking.

You can implement a file-like object by coding your own class (as covered in Chapter 4) and defining the specific methods needed by client code, such as `read`. A file-like object *fl* need not implement all the attributes and methods of a true file object *f*. If you can determine which methods the client code calls on *fl*, you can choose to implement only that subset. For example, when *fl* is only going to be written, *fl* doesn't need "reading" methods, such as `read`, `readline`, and `readlines`.

If the main reason you want a file-like object instead of a real file object is to keep the data in memory, rather than on disk, use the `io` module's classes `StringIO` or `BytesIO`, covered in "In-Memory Files: io.StringIO and io.BytesIO" on page 334. These classes supply file objects that hold data in memory and largely behave polymorphically to other file objects. If you're running multiple processes that you want to communicate via file-like objects, consider `mmap`, covered in Chapter 15.

The tempfile Module

The `tempfile` module lets you create temporary files and directories in the most secure manner afforded by your platform. Temporary files are often a good idea when you're dealing with an amount of data that might not comfortably fit in memory, or when your program must write data that another process later uses.

The order of the parameters for the functions in this module is a bit confusing: to make your code more readable, always call these functions with named-argument syntax. The `tempfile` module exposes the functions and classes outlined in Table 11-3.

Table 11-3. Functions and classes of the `tempfile` module

`mkdtemp`	`mkdtemp(suffix=None, prefix=None, dir=None)` Securely creates a new temporary directory that is readable, writable, and searchable only by the current user, and returns the absolute path to the temporary directory. You can optionally pass arguments to specify strings to use as the start (`prefix`) and end (`suffix`) of the temporary file's filename, and the path to the directory in which the temporary file is created (`dir`). Ensuring that the temporary directory is removed when you're done with it is your program's responsibility.

`mkdtemp` *(cont.)*	Here is a typical usage example that creates a temporary directory, passes its path to another function, and finally ensures the directory (and all contents) are removed:
	`import tempfile, shutil`
	`path = tempfile.mkdtemp()`
	`try:`
	`    use_dirpath(path)`
	`finally:`
	`    shutil.rmtree(path)`

`mkstemp`	`mkstemp(suffix=None, prefix=None, dir=None, text=False)`
	Securely creates a new temporary file that is readable and writable only by the current user, is not executable, and is not inherited by subprocesses; returns a pair (*fd*, *path*), where *fd* is the file descriptor of the temporary file (as returned by `os.open`, covered in Table 11-18) and the string *path* is the absolute path to the temporary file. The optional arguments `suffix`, `prefix`, and `dir` are like for the function `mkdtemp`. If you want the temporary file to be a text file, explicitly pass the argument `text=True`.
	Ensuring that the temporary file is removed when you're done using it is up to you. `mkstemp` is not a context manager, so you can't use a **`with`** statement; it's best to use **`try`**/**`finally`** instead. Here is a typical usage example that creates a temporary text file, closes it, passes its path to another function, and finally ensures the file is removed:
	`import tempfile, os`
	`fd, path = tempfile.mkstemp(suffix='.txt',`
	`                           text=True)`
	`try:`
	`    os.close(fd)`
	`    use_filepath(path)`
	`finally:`
	`    os.unlink(path)`

`Named Temporary File`	`NamedTemporaryFile(mode='w+b', bufsize=-1, suffix=None, prefix=None, dir=None)` Like `TemporaryFile` (covered later in this table), except that the temporary file does have a name on the filesystem. Use the `name` attribute of the file object to access that name. Some platforms (mainly Windows) do not allow the file to be opened again; therefore, the usefulness of the name is limited if you want to ensure that your program works cross-platform. If you need to pass the temporary file's name to another program that opens the file, you can use the function `mkstemp` instead of `NamedTemporaryFile` to guarantee correct cross-platform behavior. Of course, when you choose to use `mkstemp`, you do have to take care to ensure the file is removed when you're done with it. The file object returned from `NamedTemporaryFile` is a context manager, so you can use a `with` statement.
`Spooled Temporary File`	`SpooledTemporaryFile(mode='w+b', bufsize=-1, suffix=None, prefix=None, dir=None)` Like `TemporaryFile` (see below), except that the file object that `SpooledTemporaryFile` returns can stay in memory, if space permits, until you call its `fileno` method (or its `rollover` method, which ensures the file gets written to disk, whatever its size). As a result, performance can be better with `SpooledTemporaryFile`, as long as you have enough memory that's not otherwise in use.

`Temporary Directory`	`TemporaryDirectory(suffix=None, prefix=None, dir=None, ignore_cleanup_errors=False)` Creates a temporary directory, like `mkdtemp` (passing the optional arguments `suffix`, `prefix`, and `dir`). The returned directory object is a context manager, so you can use a **`with`** statement to ensure it's removed as soon as you're done with it. Alternatively, when you're not using it as a context manager, use its built-in class method `cleanup` (*not* `shutil.rmtree`) to explicitly remove and clean up the directory. Set `ignore_cleanup_errors` to **`True`** to ignore unhandled exceptions during cleanup. The temporary directory and its contents are removed as soon as the directory object is closed (whether implicitly on garbage collection or explicitly by a `cleanup` call).
`Temporary File`	`TemporaryFile(mode='w+b', bufsize=-1, suffix=None, prefix=None, dir=None)` Creates a temporary file with `mkstemp` (passing to `mkstemp` the optional arguments `suffix`, `prefix`, and `dir`), makes a file object from it with `os.fdopen`, covered in Table 11-18 (passing to `fdopen` the optional arguments `mode` and `bufsize`), and returns the file object. The temporary file is removed as soon as the file object is closed (implicitly or explicitly). For greater security, the temporary file has no name on the filesystem, if your platform allows that (Unix-like platforms do; Windows doesn't). The file object returned from `TemporaryFile` is a context manager, so you can use a **`with`** statement to ensure it's removed as soon as you're done with it.

Auxiliary Modules for File I/O

File objects supply the functionality needed for file I/O. Other Python library modules, however, offer convenient supplementary functionality, making I/O even easier and handier in several important cases. We'll look at two of those modules here.

The fileinput Module

The `fileinput` module lets you loop over all the lines in a list of text files. Performance is good—comparable to the performance of direct iteration on each file—since buffering is used to minimize I/O. You can therefore use this module for line-oriented file input whenever you find its rich functionality convenient, with no worry about performance. The key function of the module is `input`; `fileinput` also supplies a `FileInput` class whose methods support the same functionality. Both are described in Table 11-4.

Table 11-4. Key classes and functions of the `fileinput` module

`FileInput`	**`class`** `FileInput(files=None, inplace=False, backup='', mode='r', openhook=None, encoding=None, errors=None)` Creates and returns an instance *f* of class `FileInput`. The arguments are the same as for `fileinput.input` covered next, and methods of *f* have the same names, arguments, and semantics as the other functions of the `fileinput` module (see Table 11-5). *f* also supplies a `readline` method, which reads and returns the next line. Use the `FileInput` class to nest or mix loops that read lines from multiple sequences of files.

`input`	`input(files=None, inplace=False, backup='', mode='r', openhook=None, encoding=None, errors=None)` Returns an instance of `FileInput`, an iterable yielding lines in `files`; that instance is the global state, so all other functions of the `fileinput` module (see Table 11-5) operate on the same shared state. Each function of the `fileinput` module corresponds directly to a method of the class `FileInput`. `files` is a sequence of filenames to open and read one after the other, in order. When `files` is a string, it's a single filename to open and read. When `files` is **None**, `input` uses `sys.argv[1:]` as the list of filenames. The filename `'-'` means standard input (`sys.stdin`). When the sequence of filenames is empty, `input` reads `sys.stdin` instead. When `inplace` is **False** (the default), `input` just reads the files. When `inplace` is **True**, `input` moves each file being read (except standard input) to a backup file and redirects standard output (`sys.stdout`) to write to a new file with the same path as the original one of the file being read. This way, you can simulate overwriting files in place. If `backup` is a string that starts with a dot, `input` uses `backup` as the extension of the backup files and does not remove the backup files. If `backup` is an empty string (the default), `input` uses *.bak* and deletes each backup file as the input files are closed. The keyword argument `mode` may be `'r'`, the default, or `'rb'`. You may optionally pass an `openhook` function to use as an alternative to `io.open`. For example, `openhook=fileinput.hook_compressed` decompresses any input file with extension *.gz* or *.bz2* (not compatible with `inplace=True`). You can write your own `openhook` function to decompress other file types, for example using LZMA decompression[a] for *.xz* files; use the Python source for `fileinput.hook_compressed` as a template. **3.10+** You can also pass `encoding` and `errors`, which will be passed to the hook as keyword arguments .

[a] LZMA support may require building Python with optional additional libraries.

The functions of the `fileinput` module listed in Table 11-5 work on the global state created by `fileinput.input`, if any; otherwise, they raise `RuntimeError`.

Table 11-5. Additional functions of the `fileinput` module

`close`	`close()` Closes the whole sequence so that iteration stops and no file remains open.
`filelineno`	`filelineno()` Returns the number of lines read so far from the file now being read. For example, returns `1` if the first line has just been read from the current file.
`filename`	`filename()` Returns the name of the file now being read, or **None** if no line has been read yet.
`isfirstline`	`isfirstline()` Returns **True** or **False**, just like `filelineno() == 1`.
`isstdin`	`isstdin()` Returns **True** when the current file being read is `sys.stdin`; otherwise, returns **False**.

`lineno`	`lineno()` Returns the total number of lines read since the call to `input`.
`nextfile`	`nextfile()` Closes the file being read: the next line to read is the first one of the next file.

Here's a typical example of using `fileinput` for a "multifile search and replace," changing one string into another throughout the text files whose names were passed as command-line arguments to the script:

```
import fileinput
for line in fileinput.input(inplace=True):
    print(line.replace('foo', 'bar'), end='')
```

In such cases it's important to include the `end=''` argument to `print`, since each `line` has its line-end character `\n` at the end, and you need to ensure that `print` doesn't add another (or else each file would end up "double-spaced").

You may also use the `FileInput` instance returned by `fileinput.input` as a context manager. Just as with `io.open`, this will close all files opened by the `FileInput` upon exiting the **`with`** statement, even if an exception occurs:

```
with fileinput.input('file1.txt', 'file2.txt') as infile:
    dostuff(infile)
```

The struct Module

The `struct` module lets you pack binary data into a bytestring, and unpack the bytes of such a bytestring back into the Python data they represent. This is useful for many kinds of low-level programming. Often, you use `struct` to interpret data records from binary files that have some specified format, or to prepare records to write to such binary files. The module's name comes from C's keyword `struct`, which is usable for related purposes. On any error, functions of the module `struct` raise exceptions that are instances of the exception class `struct.error`.

The `struct` module relies on *struct format strings* following a specific syntax. The first character of a format string gives the byte order, size, and alignment of the packed data; the options are listed in Table 11-6.

Table 11-6. Possible first characters in a `struct` format string

Character	Meaning
`@`	Native byte order, native data sizes, and native alignment for the current platform; this is the default if the first character is none of the characters listed here (note that the format `P` in Table 11-7 is available only for this kind of `struct` format string). Look at the string `sys.byteorder` when you need to check your system's byte order; most CPUs today use `'little'`, but `'big'` is the "network standard" for TCP/IP, the core protocols of the internet.
`=`	Native byte order for the current platform, but standard size and alignment.
`<`	Little-endian byte order; standard size and alignment.

Character	Meaning
`>`, `!`	Big-endian/network standard byte order; standard size and alignment.

Standard sizes are indicated in Table 11-7. Standard alignment means no forced alignment, with explicit padding bytes used as needed. Native sizes and alignment are whatever the platform's C compiler uses. Native byte order can put the most significant byte at either the lowest (big-endian) or highest (little-endian) address, depending on the platform.

After the optional first character, a format string is made up of one or more format characters, each optionally preceded by a count (an integer represented by decimal digits). Common format characters are listed in Table 11-7; see the online docs for a complete list. For most format characters, the count means repetition (e.g., `'3h'` is exactly the same as `'hhh'`). When the format character is `s` or `p`—that is, a bytestring—the count is not a repetition: it's the total number of bytes in the string. You can freely use whitespace between formats, but not between a count and its format character. The format `s` means a fixed-length bytestring as long as its count (the Python string is truncated, or padded with copies of the null byte `b'\0'`, if needed). The format `p` means a "Pascal-like" bytestring: the first byte is the number of significant bytes that follow, and the actual contents start from the second byte. The count is the total number of bytes, including the length byte.

Table 11-7. Common format characters for `struct`

Character	C type	Python type	Standard size
`B`	`unsigned char`	`int`	1 byte
`b`	`signed char`	`int`	1 byte
`c`	`char`	`bytes` (length 1)	1 byte
`d`	`double`	`float`	8 bytes
`f`	`float`	`float`	4 bytes
`H`	`unsigned short`	`int`	2 bytes
`h`	`signed short`	`int`	2 bytes
`I`	`unsigned int`	`long`	4 bytes
`i`	`signed int`	`int`	4 bytes
`L`	`unsigned long`	`long`	4 bytes
`l`	`signed long`	`int`	4 bytes
`P`	`void*`	`int`	N/A
`p`	`char[]`	`bytes`	N/A
`s`	`char[]`	`bytes`	N/A
`x`	`padding byte`	No value	1 byte

The `struct` module supplies the functions covered in Table 11-8.

Table 11-8. Functions of the `struct` module

`calcsize`	`calcsize(`*`fmt`*`, /)` Returns the size, in bytes, corresponding to format string *`fmt`*.
`iter_unpack`	`iter_unpack(`*`fmt`*`, `*`buffer`*`, /)` Unpacks iteratively from *`buffer`* per format string *`fmt`*. Returns an iterator that will read equally sized chunks from *`buffer`* until all its contents are consumed; each iteration yields a tuple as specified by *`fmt`*. *`buffer`*'s size must be a multiple of the size required by the format, as reflected in `struct.calcsize(`*`fmt`*`)`.
`pack`	`pack(`*`fmt`*`, *`*`values`*`, /)` Packs the values per format string *`fmt`*, and returns the resulting bytestring. *`values`* must match in number and type the values required by *`fmt`*.
`pack_into`	`pack_into(`*`fmt`*`, `*`buffer`*`, `*`offset`*`, *`*`values`*`, /)` Packs the values per format string *`fmt`* into writable buffer *`buffer`* (usually an instance of `bytearray`) starting at index *`offset`*. *`values`* must match in number and type the values required by *`fmt`*. `len(buffer[offset:])` must be `>=struct.calcsize(`*`fmt`*`)`.
`unpack`	`unpack(`*`fmt`*`, `*`s`*`, /)` Unpacks bytestring *`s`* per format string *`fmt`*, and returns a tuple of values (if just one value, a one-item tuple). `len(`*`s`*`)` must equal `struct.calcsize(`*`fmt`*`)`.
`unpack_from`	`unpack_from(`*`fmt`*`, /, buffer, offset=0)` Unpacks bytestring (or other readable buffer) `buffer`, starting from offset `offset`, per format string *`fmt`*, returning a tuple of values (if just one value, a one-item tuple). `len(buffer[offset:])` must be `>=struct.calcsize(`*`fmt`*`)`.

The `struct` module also offers a `Struct` class, which is instantiated with a format string as an argument. Instances of this class implement `pack`, `pack_into`, `unpack`, `unpack_from`, and `iter_unpack` methods corresponding to the functions described in the preceding table; they take the same arguments as the corresponding module functions, but omitting the *`fmt`* argument, which was provided on instantiation. This allows the class to compile the format string once and reuse it. Struct objects also have a `format` attribute that holds the format string for the object, and a `size` attribute that holds the calculated size of the structure.

In-Memory Files: io.StringIO and io.BytesIO

You can implement file-like objects by writing Python classes that supply the methods you need. If all you want is for data to reside in memory, rather than in a file as seen by the operating system, use the classes `StringIO` or `BytesIO` of the `io` module. The difference between them is that instances of `StringIO` are text-mode files, so reads and writes consume or produce text strings, while instances of `BytesIO` are binary files, so reads and writes consume or produce bytestrings. These classes are especially useful in tests and other applications where program output should be redirected for buffering or journaling; "The print Function" on page 369 includes a useful context manager example, `redirect`, that demonstrates this.

When you instantiate either class you can optionally pass a string argument, respectively `str` or `bytes`, to use as the initial content of the file. Additionally, you can pass the argument `newline='\n'` to `StringIO` (but not `BytesIO`) to control how line endings are handled (like in `TextIoWrapper`); if `newline` is `None`, newlines are written as `\n` on all platforms. In addition to the methods described in Table 11-2, an instance *f* of either class supplies one extra method:

`getvalue`	`getvalue()` Returns the current data contents of *f* as a string (text or bytes). You cannot call *f*`.getvalue` after you call *f*`.close`: `close` frees the buffer that *f* internally keeps, and `getvalue` needs to return the buffer as its result.

Archived and Compressed Files

Storage space and transmission bandwidth are increasingly cheap and abundant, but in many cases you can save such resources, at the expense of some extra computational effort, by using compression. Computational power grows cheaper and more abundant even faster than some other resources, such as bandwidth, so compression's popularity keeps growing. Python makes it easy for your programs to support compression. We don't cover the details of compression in this book, but you can find details on the relevant standard library modules in the online docs.

The rest of this section covers "archive" files (which collect in a single file a collection of files and optionally directories), which may or may not be compressed. Python's stdlib offers two modules to handle two very popular archive formats: `tarfile` (which, by default, does not compress the files it bundles), and `zipfile` (which, by default, does compress the files it bundles).

The tarfile Module

The `tarfile` module lets you read and writeTAR files (archive files compatible with those handled by popular archiving programs such as `tar`), optionally with gzip, bzip2, or LZMA compression. TAR files are typically named with a *.tar* or *.tar.(compression type)* extension. **3.8+** The default format of new archives is POSIX.1-2001 (pax). **`python -m tarfile`** offers a useful command-line interface to the module's functionality: run it without arguments to get a brief help message.

The `tarfile` module supplies the functions listed in Table 11-9. When handling invalid TAR files, functions of `tarfile` raise instances of `tarfile.TarError`.

Table 11-9. Classes and functions of the `tarfile` module

`is_tarfile`	`is_tarfile(`*`filename`*`)` Returns **`True`** when the file named by *`filename`* (which may be a `str`, **3.9+** or a file or file-like object) appears to be a valid TAR file (possibly with compression), judging by the first few bytes; otherwise, returns **`False`**.
`open`	`open(name=`**`None`**`, mode='r', fileobj=`**`None`**`, bufsize=10240, **`*`kwargs`*`)` Creates and returns a `TarFile` instance *f* to read or create a TAR file through file-like object `fileobj`. When `fileobj` is **`None`**, `name` may be a string naming a file or a path-like object; `open` opens the file with the given `mode` (by default, `'r'`), and *f* wraps the resulting file object. `open` may be used as a context manager (e.g., **`with`** `tarfile.open(...)` **`as`** *f*). **f.close may not close fileobj** Calling *`f`*`.close` does *not* close `fileobj` when *f* was opened with a `fileobj` that is not **`None`**. This behavior of *`f`*`.close` is important when `fileobj` is an instance of `io.BytesIO`: you can call `fileobj.getvalue` after *`f`*`.close` to get the archived and possibly compressed data as a string. This behavior also means that you have to call `fileobj.close` explicitly after calling *`f`*`.close`. `mode` can be `'r'` to read an existing TAR file with whatever compression it has (if any); `'w'` to write a new TAR file, or truncate and rewrite an existing one, without compression; or `'a'` to append to an existing TAR file, without compression. Appending to compressed TAR files is not supported. To write a new TAR file with compression, `mode` can be `'w:gz'` for gzip compression, `'w:bz2'` for bzip2 compression, or `'w:xz'` for LZMA compression. You can use mode strings `'r:'` or `'w:'` to read or write uncompressed, nonseekable TAR files using a buffer of `bufsize` bytes; for reading TAR files use plain `'r'`, since this will automatically uncompress as necessary. In the mode strings specifying compression, you can use a vertical bar (`|`) instead of a colon (`:`) to force sequential processing and fixed-size blocks; this is useful in the (admittedly very unlikely) case that you ever find yourself handling a tape device!

The TarFile class

TarFile is the underlying class for most tarfile methods, but is not used directly. A TarFile instance *f*, created using tarfile.open, supplies the methods detailed in Table 11-10.

Table 11-10. Methods of a TarFile instance f

add	*f*.add(*name*, arcname=**None**, recursive=**True**, *, filter=**None**) Adds to archive *f* the file named by *name* (can be any type of file, a directory, or a symbolic link). When arcname is not **None**, it's used as the archive member name in lieu of *name*. When *name* is a directory, and recursive is **True**, add recursively adds the whole filesystem subtree rooted in that directory in sorted order. The optional (named-only) argument filter is a function that is called on each object to be added. It takes a TarInfo object argument and returns either the (possibly modified) TarInfo object, or **None**. In the latter case the add method excludes this TarInfo object from the archive.
addfile	*f*.addfile(*tarinfo*, fileobj=**None**) Adds to archive *f* a TarInfo object *tarinfo*. If fileobj is not **None**, the first *tarinfo*.size bytes of binary file-like object fileobj are added.
close	*f*.close() Closes archive *f*. You must call close, or else an incomplete, unusable TAR file might be left on disk. Such mandatory finalization is best performed with a **try**/**finally**, as covered in "try/finally" on page 198, or, even better, a **with** statement, covered in "The with Statement and Context Managers" on page 201. Calling *f*.close does *not* close fileobj if *f* was created with a non-**None** fileobj. This matters especially when fileobj is an instance of io.BytesIO: you can call fileobj.getvalue after *f*.close to get the compressed data string. So, you always have to call fil eobj.close (explicitly, or implicitly by using a **with** statement) *after* *f*.close.
extract	*f*.extract(*member*, path='', set_attrs=**True**, numeric_owner=**False**) Extracts the archive member identified by *member* (a name or a TarInfo instance) into a corresponding file in the directory (or path-like object) named by path (the current directory by default). If set_attrs is **True**, the owner and timestamps will be set as they were saved in the TAR file; otherwise, the owner and timestamps for the extracted file will be set using the current user and time values. If numeric_owner is **True**, the UID and GID numbers from the TAR file are used to set the owner/group for the extracted files; otherwise, the named values from the TAR file are used. (The online docs recommend using extractall over calling extract directly, since extractall does additional error handling internally.)

`extractall`	`f.extractall(path='.', members=None, numeric_owner=False)` Similar to calling `extract` on each member of TAR file *f*, or just those listed in the `members` argument, with additional error checking for `chown`, `chmod`, and `utime` errors that occur while writing the extracted members.

Don't Use extractall on a Tarfile from an Untrusted Source

`extractall` does not check the paths of extracted files, so there is a risk that an extracted file will have an absolute path (or include one or more `..` components) and thus overwrite a potentially sensitive file.[a] It is best to read each member individually and only extract it if it has a safe path (i.e., no absolute paths or relative paths with any `..` path component).

`extractfile`	`f.extractfile(member)` Extracts the archive member identified by *`member`* (a name or a `TarInfo` instance) and returns an `io.BufferedReader` object with the methods `read`, `readline`, `readlines`, `seek`, and `tell`.
`getmember`	`f.getmember(name)` Returns a `TarInfo` instance with information about the archive member named by the string *`name`*.
`getmembers`	`f.getmembers()` Returns a list of `TarInfo` instances, one for each member in archive *f*, in the same order as the entries in the archive itself.
`getnames`	`f.getnames()` Returns a list of strings, the names of each member in archive *f*, in the same order as the entries in the archive itself.
`gettarinfo`	`f.gettarinfo(name=None, arcname=None, fileobj=None)` Returns a `TarInfo` instance with information about the open file object `fileobj`, when not **None**, or else the existing file whose path is the string `name`. `name` may be a path-like object. When `arcname` is not **None**, it's used as the `name` attribute of the resulting `TarInfo` instance.
`list`	`f.list(verbose=True, *, members=None)` Outputs a directory of the archive *f* to `sys.stdout`. If the optional argument `verbose` is **`False`**, outputs only the names of the archive's members. If the optional argument `members` is given, it must be a subset of the list returned by `getmembers`.
`next`	`f.next()` Returns the next available archive member as a `TarInfo` instance; if none are available, returns **None**.

[a] Described further in CVE-2007-4559.

The TarInfo class

The methods `getmember` and `getmembers` of `TarFile` instances return instances of `TarInfo`, supplying information about members of the archive. You can also build a `TarInfo` instance with a `TarFile` instance's method `gettarinfo`. The *`name`* argument may be a path-like object. The most useful attributes and methods supplied by a `TarInfo` instance *`t`* are listed in Table 11-11.

Table 11-11. Useful attributes of a `TarInfo` instance `t`

`isdir()`	Returns **`True`** if the file is a directory
`isfile()`	Returns **`True`** if the file is a regular file
`issym()`	Returns **`True`** if the file is a symbolic link
`linkname`	Target file's name (a string), when *`t`*`.type` is `LNKTYPE` or `SYMTYPE`
`mode`	Permission and other mode bits of the file identified by *`t`*
`mtime`	Time of last modification of the file identified by *`t`*
`name`	Name in the archive of the file identified by *`t`*
`size`	Size, in bytes (uncompressed), of the file identified by *`t`*
`type`	File type—one of many constants that are attributes of the `tarfile` module (`SYMTYPE` for symbolic links, `REGTYPE` for regular files, `DIRTYPE` for directories, and so on; see the online docs for a complete list)

The zipfile Module

The `zipfile` module can read and write ZIP files (i.e., archive files compatible with those handled by popular compression programs such as `zip` and `unzip`, `pkzip` and `pkunzip`, `WinZip`, and so on, typically named with a *.zip* extension). **`python -m zipfile`** offers a useful command-line interface to the module's functionality: run it without further arguments to get a brief help message.

Detailed information about ZIP files is available on the PKWARE and Info-ZIP websites. You need to study that detailed information to perform advanced ZIP file handling with `zipfile`. If you do not specifically need to interoperate with other programs using the ZIP file standard, the modules `lzma`, `gzip`, and `bz2` are usually better ways to deal with compression, as is `tarfile` to create (optionally compressed) archives.

The `zipfile` module can't handle multidisk ZIP files, and cannot create encrypted archives (it can decrypt them, albeit rather slowly). The module also cannot handle archive members using compression types besides the usual ones, known as *stored* (a file copied to the archive without compression) and *deflated* (a file compressed using the ZIP format's default algorithm). `zipfile` also handles the bzip2 and LZMA compression types, but beware: not all tools can handle those, so if you use them you're sacrificing some portability to get better compression.

The `zipfile` module supplies function `is_zipfile` and class `Path`, as listed in Table 11-12. In addition, it supplies classes `ZipFile` and `ZipInfo`, described later. For errors related to invalid ZIP files, functions of `zipfile` raise exceptions that are instances of the exception class `zipfile.error`.

Table 11-12. Auxiliary function and class of the `zipfile` module

`is_zipfile`	`is_zipfile(`*`file`*`)` Returns **`True`** when the file named by string, path-like object, or file-like object *`file`* seems to be a valid ZIP file, judging by the first few and last bytes of the file; otherwise, returns **`False`**.
`Path`	**`class`** `Path(`*`root`*`, at='')` **3.8+** A `pathlib`-compatible wrapper for ZIP files. Returns a `pathlib.Path` object *`p`* from *`root`*, a ZIP file (which may be a `ZipFile` instance or file suitable for passing to the `ZipFile` constructor). The string argument `at` is a path to specify the location of *`p`* in the ZIP file: the default is the root. *`p`* exposes several `pathlib.Path` methods: see the online docs for details.

The ZipFile class

The main class supplied by `zipfile` is `ZipFile`. Its constructor has the following signature:

`ZipFile`	**`class`** `ZipFile(`*`file`*`, mode='r', compression=zipfile.ZIP_STORED, allowZip64=`**`True`**`, compresslevel=`**`None`**`, *, strict_timestamps=`**`True`**`)` Opens a ZIP file named by *`file`* (a string, file-like object, or path-like object). `mode` can be `'r'` to read an existing ZIP file, `'w'`, to write a new ZIP file or truncate and rewrite an existing one, or `'a'` to append to an existing file. It can also be `'x'`, which is like `'w'` but raises an exception if the ZIP file already existed—here, `'x'` stands for "exclusive." When `mode` is `'a'`, *`file`* can name either an existing ZIP file (in which case new members are added to the existing archive) or an existing non-ZIP file. In the latter case, a new ZIP file-like archive is created and appended to the existing file. The main purpose of this latter case is to let you build an executable file that unpacks itself when run. The existing file must then be a pristine copy of a self-unpacking executable prefix, as supplied by *www.info-zip.org* and by other purveyors of ZIP file compression tools. `compression` is the ZIP compression method to use in writing the archive: `ZIP_STORED` (the default) requests that the archive use no compression, and `ZIP_DEFLATED` requests that the archive use the *deflation* mode of compression (the most usual and effective compression approach used in ZIP files). It can also be `ZIP_BZIP2` or `ZIP_LZMA` (sacrificing portability for more compression; these require the `bz2` or `lzma` module, respectively). Unrecognized values will raise `NotImplementedError`.

`ZipFile` *(cont.)*	When `allowZip64` is **`True`** (the default), the `ZipFile` instance is allowed to use the ZIP64 extensions to produce an archive larger than 4 GB; otherwise, any attempt to produce such a large archive raises a `LargeZipFile` exception. `compresslevel` is an integer (ignored when using `ZIP_STORED` or `ZIP_LZMA`) from `0` for `ZIP_DEFLATED` (`1` for `ZIP_BZIP2`), which requests modest compression but fast operation, to `9` to request the best compression at the cost of more computation. **3.8+** Set `strict_timestamps` to **`False`** to store files older than 1980-01-01 (sets the timestamp to 1980-01-01) or beyond 2107-12-31 (sets the timestamp to 2107-12-31).

`ZipFile` is a context manager; thus, you can use it in a **`with`** statement to ensure the underlying file gets closed when you're done with it. For example:

```
with zipfile.ZipFile('archive.zip') as z:
    data = z.read('data.txt')
```

In addition to the arguments with which it was instantiated, a `ZipFile` instance *`z`* has the attributes `fp` and `filename`, which are the file-like object *`z`* works on and its filename (if known); `comment`, the possibly empty string that is the archive's comment; and `filelist`, the list of `ZipInfo` instances in the archive. In addition, *`z`* has a writable attribute called `debug`, an `int` from `0` to `3` that you can assign to control how much debugging output to emit to `sys.stdout`:[2] from nothing when *`z`*`.debug` is `0`, to the maximum amount of information available when *`z`*`.debug` is `3`.

A `ZipFile` instance *`z`* supplies the methods listed in Table 11-13.

Table 11-13. Methods supplied by an instance z of `ZipFile`

`close`	`close()` Closes archive file *`z`*. Make sure to call *`z`*`.close()`, or an incomplete and unusable ZIP file might be left on disk. Such mandatory finalization is generally best performed with a **`try`**/**`finally`** statement, as covered in "try/finally" on page 198, or—even better—a **`with`** statement, covered in "The with Statement and Context Managers" on page 201.
`extract`	`extract(`*`member`*`, path=`**`None`**`, pwd=`**`None`**`)` Extracts an archive member to disk, to the directory or path-like object `path` or, by default, to the current working directory; *`member`* is the member's full name, or an instance of `ZipInfo` identifying the member. `extract` normalizes path info within *`member`*, turning absolute paths into relative ones, removing any `..` component, and, on Windows, turning characters that are illegal in filenames into underscores (_). pwd, if present, is the password to use to decrypt an encrypted member. `extract` returns the path to the file it has created (or overwritten if it already existed), or to the directory it has created (or left alone if it already existed). Calling `extract` on a closed `ZipFile` raises `ValueError`.

2 Alas, yes—not `sys.stderr`, as common practice and logic would dictate!

`extractall`	`extractall(path=`**`None`**`, members=`**`None`**`, pwd=`**`None`**`)` Extracts archive members to disk (by default, all of them), to directory or path- like object `path` or, by default, to the current working directory; `members` optionally limits which members to extract, and must be a subset of the list of strings returned by *`z`*`.namelist`. `extractall` normalizes path info within members it extracts, turning absolute paths into relative ones, removing any `..` component, and, on Windows, turning characters that are illegal in filenames into underscores (_). `pwd`, if present, is the password to use to decrypt encrypted members, if any.
`getinfo`	`getinfo(`*`name`*`)` Returns a `ZipInfo` instance that supplies information about the archive member named by the string *name*.
`infolist`	`infolist()` Returns a list of `ZipInfo` instances, one for each member in archive *z*, in the same order as the entries in the archive.
`namelist`	`namelist()` Returns a list of strings, the name of each member in archive *z*, in the same order as the entries in the archive.
`open`	`open(`*`name`*`, mode='r', pwd=`**`None`**`, *, force_zip64=`**`False`**`)` Extracts and returns the archive member identified by *name* (a member name string or `ZipInfo` instance) as a (maybe read-only) file-like object. *mode* may be `'r'` or `'w'`. `pwd`, if present, is the password to use to decrypt an encrypted member. Pass `force_zip64=`**`True`** when an unknown file size may exceed 2 GiB, to ensure the header format is capable of supporting large files. When you know in advance the large file size, use a `ZipInfo` instance for *name*, with `file_size` set appropriately.
`printdir`	`printdir()` Outputs a textual directory of the archive *z* to `sys.stdout`.
`read`	`read(`*`name`*`, `*`pwd`*`)` Extracts the archive member identified by *name* (a member name string or `ZipInfo` instance) and returns the bytestring of its contents (raises `ValueError` if called on a closed `ZipFile`). *pwd*, if present, is the password to use to decrypt an encrypted member.
`setpassword`	`setpassword(`*`pwd`*`)` Sets string *pwd* as the default password to use to decrypt encrypted files.
`testzip`	`testzip()` Reads and checks the files in archive *z*. Returns a string with the name of the first archive member that is damaged, or **None** if the archive is intact.
`write`	`write(`*`filename`*`, arcname=`**`None`**`, compress_type=`**`None`**`, compresslevel=`**`None`**`)` Writes the file named by string *filename* to archive *z*, with archive member name `arcname`. When `arcname` is **None**, `write` uses *filename* as the archive member name. When `compress_type` or `compresslevel` is **None** (the default), `write` uses *z*'s compression type and level; otherwise, `compress_type` and/or `compresslevel` specify how to compress the file. *z* must be opened for modes `'w'`, `'x'`, or `'a'`; otherwise `ValueError` is raised.

writestr	`writestr(zinfo_arc, data, compress_type=None, compresslevel=None)` Adds a member to archive *z* using the metadata specified by *zinfo_arc* and the data in *data*. *zinfo_arc* must be either a `ZipInfo` instance specifying at least *filename* and *date_time*, or a string to be used as the archive member name with the date and time are set to the current moment. *data* is an instance of `bytes` or `str`. When `compress_type` or `compresslevel` is **None** (the default), `writestr` uses *z*'s compression type and level; otherwise, `compress_type` and/or `compresslevel` specify how to compress the file. *z* must be opened for modes `'w'`, `'x'`, or `'a'`; otherwise `ValueError` is raised.
	When you have data in memory and need to write the data to the ZIP file archive *z*, it's simpler and faster to use `z.writestr` than `z.write`. The latter would require you to write the data to disk first and later remove the useless disk file; with the former you can just code:
	`import zipfile`
	`with zipfile.ZipFile('z.zip', 'w') as zz:`
	`    data = 'four score\nand seven\nyears ago\n'`
	`    zz.writestr('saying.txt', data)`
	Here's how you can print a list of all files contained in the ZIP file archive created by the previous example, followed by each file's name and contents:
	`with zipfile.ZipFile('z.zip') as zz:`
	`    zz.printdir()`
	`    for name in zz.namelist():`
	`        print(f'{name}: {zz.read(name)!r}')`

The ZipInfo class

The methods `getinfo` and `infolist` of `ZipFile` instances return instances of class `ZipInfo` to supply information about members of the archive. Table 11-14 lists the most useful attributes supplied by a `ZipInfo` instance *z*.

Table 11-14. Useful attributes of a `ZipInfo` instance z

comment	A string that is a comment on the archive member
compress_size	The size, in bytes, of the compressed data for the archive member
compress_type	An integer code recording the type of compression of the archive member
date_time	A tuple of six integers representing the time of the last modification to the file: the items are year (>=1980), month, day (1+), hour, minute, second (0+)
file_size	The size, in bytes, of the uncompressed data for the archive member
filename	The name of the file in the archive

The os Module

`os` is an umbrella module presenting a nearly uniform cross-platform view of the capabilities of various operating systems. It supplies low-level ways to create and handle files and directories, and to create, manage, and destroy processes. This section covers filesystem-related functions of `os`; "Running Other Programs with the os Module" on page 478 covers process-related functions. Most of the time you can use other modules at higher levels of abstraction and gain productivity, but understanding what is "underneath" in the low-level `os` module can still be quite useful (hence our coverage).

The `os` module supplies a `name` attribute, a string that identifies the kind of platform on which Python is being run. Common values for `name` are `'posix'` (all kinds of Unix-like platforms, including Linux and macOS) and `'nt'` (all kinds of Windows platforms); `'java'` is for the old but still-missed Jython. You can exploit some unique capabilities of a platform through functions supplied by `os`. However, this book focuses on cross-platform programming, not platform-specific functionality, so we cover neither parts of `os` that exist only on one platform, nor platform-specific modules: functionality covered in this book is available at least on `'posix'` and `'nt'` platforms. We do, though, cover some of the differences among the ways in which a given functionality is provided on various platforms.

Filesystem Operations

Using the `os` module, you can manipulate the filesystem in a variety of ways: creating, copying, and deleting files and directories; comparing files; and examining filesystem information about files and directories. This section documents the attributes and methods of the `os` module that you use for these purposes, and covers some related modules that operate on the filesystem.

Path-string attributes of the os module

A file or directory is identified by a string, known as its *path*, whose syntax depends on the platform. On both Unix-like and Windows platforms, Python accepts Unix syntax for paths, with a slash (`/`) as the directory separator. On non-Unix-like platforms, Python also accepts platform-specific path syntax. On Windows, in particular, you may use a backslash (`\`) as the separator. However, you then need to double up each backslash as `\\` in string literals, or use raw string literal syntax (as covered in "Strings" on page 44); you also needlessly lose portability. Unix path syntax is handier and usable everywhere, so we strongly recommend that you *always* use it. In the rest of this chapter, we use Unix path syntax in both explanations and examples.

The `os` module supplies attributes that provide details about path strings on the current platform, detailed in Table 11-15. You should typically use the higher-level path manipulation operations covered in "The os.path Module" on page 354[3] rather than lower-level string operations based on these attributes. However, these attributes may be useful at times.

3 Or, even better, the even-higher-level `pathlib` module, covered later in this chapter.

Table 11-15. Attributes supplied by the `os` module

`curdir`	The string that denotes the current directory (`'.'` on Unix and Windows)
`defpath`	The default search path for programs, used if the environment lacks a `PATH` environment variable
`extsep`	The string that separates the extension part of a file's name from the rest of the name (`'.'` on Unix and Windows)
`linesep`	The string that terminates text lines (`'\n'` on Unix; `'\r\n'` on Windows)
`pardir`	The string that denotes the parent directory (`'..'` on Unix and Windows)
`pathsep`	The separator between paths in lists of paths expressed as strings, such as those used for the environment variable `PATH` (`':'` on Unix; `';'` on Windows)
`sep`	The separator of path components (`'/'` on Unix; `'\\'` on Windows)

Permissions

Unix-like platforms associate nine bits with each file or directory: three each for the file's owner, its group, and everybody else (aka "others" or "the world"), indicating whether the file or directory can be read, written, and executed by the given subject. These nine bits are known as the file's *permission bits*, and are part of the file's *mode* (a bit string that includes other bits that describe the file). You often display these bits in octal notation, which groups three bits per digit. For example, mode `0o664` indicates a file that can be read and written by its owner and group, and that anybody else can read, but not write. When any process on a Unix-like system creates a file or directory, the operating system applies to the specified mode a bit mask known as the process's *umask*, which can remove some of the permission bits.

Non-Unix-like platforms handle file and directory permissions in very different ways. However, the `os` functions that deal with file permissions accept a *`mode`* argument according to the Unix-like approach described in the previous paragraph. Each platform maps the nine permission bits in a way appropriate for it. For example, on Windows, which distinguishes only between read-only and read/write files and does not record file ownership, a file's permission bits show up as either `0o666` (read/write) or `0o444` (read-only). On such a platform, when creating a file, the implementation looks only at bit `0o200`, making the file read/write when that bit is `1` and read-only when it is `0`.

File and directory functions of the os module

The `os` module supplies several functions (listed in Table 11-16) to query and set file and directory status. In all versions and platforms, the argument *`path`* to any of these functions can be a string giving the path of the file or directory involved, or it can be a path-like object (in particular, an instance of `pathlib.Path`, covered later in this chapter). There are also some particularities on some Unix platforms:

- Some of the functions also support a *file descriptor* (*fd*)—an `int` denoting a file as returned, for example, by `os.open`—as the *path* argument. The module attribute `os.supports_fd` is the set of functions in the `os` module that support this behavior (the module attribute is missing on platforms lacking such support).

- Some functions support the optional keyword-only argument `follow_symlinks`, defaulting to **`True`**. When this argument is **`True`**, if *`path`* indicates a symbolic link, the function follows it to reach an actual file or directory; when it's **`False`**, the function operates on the symbolic link itself. The module attribute `os.supports_follow_symlinks`, if present, is the set of functions in the `os` module that support this argument.
- Some functions support the optional named-only argument `dir_fd`, defaulting to `None`. When `dir_fd` is present, *`path`* (if relative) is taken as being relative to the directory open at that file descriptor; when missing, *`path`* (if relative) is taken as relative to the current working directory. If *`path`* is absolute, `dir_fd` is ignored. The module attribute `os.supports_dir_fd`, if present, is the set of functions of the `os` module that support this argument.

Additionally, on some platforms the named-only argument `effective_ids`, defaulting to **`False`**, lets you choose to use effective rather than real user and group identifiers. Check whether it is available on your platform with `os.supports_effective_ids`.

Table 11-16. `os` module functions

`access`	`access(`*`path`*`, `*`mode`*`, *, dir_fd=`**`None`**`, effective_ids=`**`False`**`, follow_symlinks=`**`True`**`)` Returns **`True`** when the file or path-like object *`path`* has all of the permissions encoded in integer *`mode`*; otherwise, returns **`False`**. *`mode`* can be `os.F_OK` to test for file existence, or one or more of `os.R_OK`, `os.W_OK`, and `os.X_OK` (joined with the bitwise OR operator `|`, if more than one) to test permissions to read, write, and execute the file. If `dir_fd` is not **`None`**, `access` operates on *`path`* relative to the provided directory (if *`path`* is absolute, `dir_fd` is ignored). Pass the keyword-only argument `effective_ids=`**`True`** (the default is **`False`**) to use effective rather than real user and group identifiers (this may not work on all platforms). If you pass `follow_symlinks=`**`False`** and the last element of *`path`* is a symbolic link, `access` operates on the symbolic link itself, not on the file pointed to by the link. `access` does not use the standard interpretation for its *`mode`* argument, covered in the previous section. Rather, `access` tests only if this specific process's real user and group identifiers have the requested permissions on the file. If you need to study a file's permission bits in more detail, see the function `stat`, covered later in this table. Don't use `access` to check if a user is authorized to open a file, before opening it; this might be a security hole.
`chdir`	`chdir(`*`path`*`)` Sets the current working directory of the process to *`path`*, which may be a file descriptor or path-like object.

chmod, lchmod	`chmod(path, mode, *, dir_fd=None, follow_symlinks=True)`
	`lchmod(path, mode)`
	Changes the permissions of the file (or file descriptor or path-like object) *path*, as encoded in integer *mode*. *mode* can be zero or more of `os.R_OK`, `os.W_OK`, and `os.X_OK` (joined with the bitwise OR operator `|`, if more than one) for read, write, and execute permissions. On Unix-like platforms, *mode* can be a richer bit pattern (as covered in the previous section) to specify different permissions for user, group, and other, as well as having other special, rarely used bits defined in the module `stat` and listed in the online docs. Pass `follow_symlinks=False` (or use `lchmod`) to change permissions of a symbolic link, not the target of that link.

DirEntry	An instance *d* of class `DirEntry` supplies attributes *name* and *path*, holding the item's base name and full path, respectively, and several methods, of which the most frequently used are `is_dir`, `is_file`, and `is_symlink`. `is_dir` and `is_file` by default follow symbolic links: pass `follow_symlinks=False` to avoid this behavior. *d* avoids system calls as much as feasible, and when it needs one, it caches the results. If you need information that's guaranteed to be up-to-date, you can call `os.stat(d.path)` and use the `stat_result` instance it returns; however, this sacrifices `scandir`'s potential performance improvements. For more complete information, see the online docs.
getcwd, getcwdb	`getcwd()`, `getcwdb()` `getcwd` returns a `str`, the path of the current working directory. `getcwdb` returns a `bytes` string (3.8+ with UTF-8 encoding on Windows).
link	`link(src, dst, *, src_dir_fd=None, dst_dir_fd=None, follow_symlinks=True)` Creates a *hard* link named *dst*, pointing to *src*. Both may be path-like objects. Set `src_dir_fd` and/or `dst_dir_fd` for `link` to operate on relative paths, and pass `follow_symlinks=False` to only operate on a symbolic link, not the target of that link. To create a symbolic ("soft") link, use the `symlink` function, covered later in this table.
listdir	`listdir(path='.')` Returns a list whose items are the names of all files and subdirectories in the directory, file descriptor (referring to a directory), or path-like object `path`. The list is in arbitrary order and does *not* include the special directory names `'.'` (current directory) and `'..'` (parent directory). When `path` is of type `bytes`, the filenames returned are also of type `bytes`; otherwise, they are of type `str`. See also the alternative function `scandir`, covered later in this table, which can offer performance improvements in some cases. Don't remove or add files to the directory during the call of this function: that may produce unexpected results.

`mkdir`, `makedirs`	`mkdir(`*`path`*`, mode=0777, dir_fd=`**`None`**`)`, `makedirs(`*`path`*`, mode=0777, exist_ok=`**`False`**`)` `mkdir` creates only the rightmost directory of *`path`* and raises `OSError` if any of the previous directories in *`path`* do not exist. `mkdir` accepts `dir_fd` for paths relative to a file descriptor. `makedirs` creates all directories that are part of *`path`* and do not yet exist (pass `exist_ok=`**`True`** to avoid raising `FileExistsError`). Both functions use `mode` as permission bits of directories they create, but some platforms, and some newly created intermediate-level directories, may ignore `mode`; use `chmod` to explicitly set permissions.
`remove`, `unlink`	`remove(`*`path`*`, *, dir_fd=`**`None`**`)`, `unlink(`*`path`*`, *, dir_fd=`**`None`**`)` Removes the file or path-like object *`path`* , which may be relative to `dir_fd`. See `rmdir` later in this table to remove a directory, rather than a file. `unlink` is a synonym of `remove`.
`removedirs`	`removedirs(`*`path`*`)` Loops from right to left over the directories that are part of *`path`*, which may be a path-like object, removing each one. The loop ends when a removal attempt raises an exception, generally because a directory is not empty. `removedirs` does not propagate the exception, as long as it has removed at least one directory.
`rename`, `renames`	`rename(src, dst, *, src_dir_fd=`**`None`**`, dst_dir_fd=`**`None`**`)`, `renames(`*`src`*`, `*`dst`*`, /)` Renames ("moves") the file, path-like object, or directory named `src` to `dst`. If `dst` already exists, `rename` may either replace `dst` or raise an exception; to guarantee replacement, instead call the function `os.replace`. To use relative paths, pass `src_dir_fd` and/or `dst_dir_fd`. `renames` works like `rename`, except it creates all intermediate directories needed for *`dst`*. After renaming, `renames` removes empty directories from the path *`src`* using `removedirs`. It does not propagate any resulting exception; it's not an error if the renaming does not empty the starting directory of *`src`*. `renames` cannot accept relative path arguments.
`rmdir`	`rmdir(`*`path`*`, *, dir_fd=`**`None`**`)` Removes the empty directory or path-like object named *`path`* (which may be relative to `dir_fd`). Raises `OSError` if the removal fails, and, in particular, if the directory is not empty.
`scandir`	`scandir(path='.')` Returns an iterator yielding `os.DirEntry` instances for each item in `path`, which may be a string, a path-like object, or a file descriptor. Using `scandir` and calling each resulting item's methods to determine its characteristics can provide performance improvements compared to using `listdir` and `stat`, depending on the underlying platform. `scandir` may be used as a context manager: e.g., **`with`** `os.scandir(`*`path`*`)` **`as`** *`itr`*`:` to ensure closure of the iterator (freeing up resources) when done.

`stat`, `lstat`, `fstat`	`stat(path, *, dir_fd=None, follow_symlinks=True)`, `lstat(path, *, dir_fd=None)`, `fstat(fd)`

`stat` returns a value *x* of type `stat_result`, which provides (at least) 10 items of information about `path`. `path` may be a file, file descriptor (in this case you can use `stat(fd)` or `fstat`, which only accepts file descriptors), path-like object, or subdirectory. *`path`* may be a relative path of `dir_fd`, or a symlink (if `follow_symlinks=False`, or if using `lstat`; on Windows, all reparse points that the OS can resolve are followed unless `follow_symlinks=False`). The `stat_result` value is a tuple of values that also supports named access to each of its contained values (similar to a `collections.namedtuple`, though not implemented as such). Accessing the items of `stat_result` by their numeric indices is possible but not advisable, because the resulting code is not readable; use the corresponding attribute names instead. Table 11-17 lists the main 10 attributes of a `stat_result` instance and the meaning of the corresponding items.

Table 11-17. Items (attributes) of a `stat_result` instance

Item index	Attribute name	Meaning
0	`st_mode`	Protection and other mode bits
1	`st_ino`	Inode number
2	`st_dev`	Device ID
3	`st_nlink`	Number of hard links
4	`st_uid`	User ID of owner
5	`st_gid`	Group ID of owner
6	`st_size`	Size, in bytes
7	`st_atime`	Time of last access
8	`st_mtime`	Time of last modification
9	`st_ctime`	Time of last status change

For example, to print the size, in bytes, of file *`path`*, you can use any of:

```
import os
print(os.stat(path)[6])        # works but unclear
print(os.stat(path).st_size)  # easier to understand
print(os.path.getsize(path))  # convenience function
                              # that wraps stat
```

Time values are in seconds since the epoch, as covered in Chapter 13 (`int`, on most platforms). Platforms unable to give a meaningful value for an item use a dummy value. For other, platform-dependent attributes of `stat_result` instances, see the online docs.

`symlink`	`symlink(`*`target`*`, `*`symlink_path`*`, target_is_directory=`**`False`**`, *, dir_fd=`**`None`**`)` Creates a symbolic link named *`symlink_path`* to the file, directory, or path-like object *`target`*, which may be relative to `dir_fd`. `target_is_directory` is used only on Windows systems, to specify whether the created symlink should represent a file or a directory; this argument is ignored on non-Windows systems. (Calling `os.symlink` typically requires elevated privileges when run on Windows.)
`utime`	`utime(`*`path`*`, times=`**`None`**`, *, [`*`ns`*`, ]dir_fd=`**`None`**`, follow_symlinks=`**`True`**`)` Sets the accessed and modified times of file, directory, or path-like object *`path`*, which may be relative to `dir_fd`, and may be a symlink if `follow_symlinks=`**`False`**. If `times` is **`None`**, `utime` uses the current time. Otherwise, `times` must be a pair of numbers (in seconds since the epoch, as covered in Chapter 13) in the order `(`*`accessed`*`, `*`modified`*`)`. To specify nanoseconds instead, pass *`ns`* as `(`*`acc_ns`*`, `*`mod_ns`*`)`, where each member is an `int` expressing nanoseconds since the epoch. Do *not* specify both `times` and *`ns`*.
`walk`, `fwalk`	`walk(`*`top`*`, topdown=`**`True`**`, onerror=`**`None`**`, followlinks=`**`False`**`)`, `fwalk(top='.', topdown=`**`True`**`, onerror=`**`None`**`, *, follow_symlinks=`**`False`**`, dir_fd=`**`None`**`)` `walk` is a generator yielding an item for each directory in the tree whose root is the directory or path-like object *`top`*. When `topdown` is **`True`**, the default, `walk` visits directories from the tree's root downward; when `topdown` is **`False`**, `walk` visits directories from the tree's leaves upward. By default, `walk` catches and ignores any `OSError` exception raised during the tree-walk; set `onerror` to a callable in order to catch any `OSError` exception raised during the tree-walk and pass it as the only argument in a call to `onerror`, which may process it, ignore it, or **`raise`** it to terminate the tree-walk and propagate the exception (the filename is available as the `filename` attribute of the exception object). Each item `walk` yields is a tuple of three subitems: *`dirpath`*, a string that is the directory's path; *`dirnames`*, a list of names of subdirectories that are immediate children of the directory (special directories `'.'` and `'..'` are *not* included); and *`filenames`*, a list of names of files that are directly in the directory. If `topdown` is **`True`**, you can alter list *`dirnames`* in place, removing some items and/or reordering others, to affect the tree-walk of the subtree rooted at *`dirpath`*; `walk` iterates only on subdirectories left in *`dirnames`*, in the order in which they're left. Such alterations have no effect if `topdown` is **`False`** (in this case, `walk` has already visited all subdirectories by the time it visits the current directory and yields its item).

`walk`, `fwalk` *(cont.)*

By default, `walk` does not walk down symbolic links that resolve to directories. To get such extra walking, pass `followlinks=True`, but beware: this can cause infinite looping if a symbolic link resolves to a directory that is its ancestor. `walk` doesn't take precautions against this anomaly.

followlinks versus follow_symlinks

Note that, for `os.walk` *only*, the argument that is named `follow_symlinks` everywhere else is instead named `followlinks`.

`fwalk` (Unix only) works like `walk`, except that *`top`* may be a relative path of file descriptor `dir_fd`, and `fwalk` yields *four*-member tuples: the first three members (*`dirpath`*, *`dirnames`*, and *`filenames`*) are identical to `walk`'s yielded values, and the fourth member is *`dirfd`*, a file descriptor of *`dirpath`*. Note that both `walk` and `fwalk` default to *not* following symlinks.

File descriptor operations

In addition to the many functions covered earlier, the `os` module supplies several that work specifically with file descriptors. A *file descriptor* is an integer that the operating system uses as an opaque handle to refer to an open file. While it is usually best to use Python file objects (covered in "The io Module" on page 322) for I/O tasks, sometimes working with file descriptors lets you perform some operations faster, or (at the possible expense of portability) in ways not directly available with `io.open`. File objects and file descriptors are not interchangeable.

To get the file descriptor *`n`* of a Python file object *`f`*, call *`n`* `=` *`f`*`.fileno()`. To create a new Python file object *`f`* using an existing open file descriptor *`fd`*, use *`f`* `= os.fdopen(`*`fd`*`)`, or pass *`fd`* as the first argument of `io.open`. On Unix-like and Windows platforms, some file descriptors are preallocated when a process starts: `0` is the file descriptor for the process's standard input, `1` for the process's standard output, and `2` for the process's standard error. Calling `os` module methods such as `dup` or `close` on these preallocated file descriptors can be useful for redirecting or manipulating standard input and output streams.

The os module provides many functions for dealing with file descriptors; some of the most useful are listed in Table 11-18.

Table 11-18. Useful os module functions to deal with file descriptors

close	close(*fd*) Closes file descriptor *fd*.
closerange	closerange(*fd_low*, *fd_high*) Closes all file descriptors from *fd_low*, included, to *fd_high*, excluded, ignoring any errors that may occur.
dup	dup(*fd*) Returns a file descriptor that duplicates file descriptor *fd*.
dup2	dup2(*fd*, *fd2*) Duplicates file descriptor *fd* to file descriptor *fd2*. When file descriptor *fd2* is already open, dup2 first closes *fd2*.
fdopen	fdopen(*fd*, **a*, ***k*) Like io.open, except that *fd* *must* be an int that is an open file descriptor.
fstat	fstat(*fd*) Returns a stat_result instance *x*, with information about the file open on file descriptor *fd*. Table 11-17 covers *x*'s contents.
lseek	lseek(*fd*, *pos*, *how*) Sets the current position of file descriptor *fd* to the signed integer byte offset *pos* and returns the resulting byte offset from the start of the file. *how* indicates the reference (point 0). When *how* is os.SEEK_SET, a *pos* of 0 means the start of the file; for os.SEEK_CUR it means the current position, and for os.SEEK_END it means the end of the file. For example, lseek(*fd*, 0, os.SEEK_CUR) returns the current position's byte offset from the start of the file without affecting the current position. Normal disk files support seeking; calling lseek on a file that does not support seeking (e.g., a file open for output to a terminal) raises an exception.

open	open(*file*, *flags*, mode=0o777) Returns a file descriptor, opening or creating a file named by string *file*. When open creates the file, it uses mode as the file's permission bits. *flags* is an int, normally the bitwise OR (with operator |) of one or more of the following attributes of os: O_APPEND Appends any new data to *file*'s current contents O_BINARY Opens *file* in binary rather than text mode on Windows platforms (raises an exception on Unix-like platforms) O_CREAT Creates *file* if *file* does not already exist O_DSYNC, O_RSYNC, O_SYNC, O_NOCTTY Set the synchronization mode accordingly, if the platform supports this O_EXCL Raises an exception if *file* already exists O_NDELAY, O_NONBLOCK Opens *file* in nonblocking mode, if the platform supports this O_RDONLY, O_WRONLY, O_RDWR Opens *file* for read-only, write-only, or read/write access, respectively (mutually exclusive: exactly one of these attributes *must* be in *flags*) O_TRUNC Throws away previous contents of *file* (incompatible with O_RDONLY)
pipe	pipe() Creates a pipe and returns a pair of file descriptors (*r_fd*, *w_fd*), respectively open for reading and writing.
read	read(*fd*, *n*) Reads up to *n* bytes from file descriptor *fd* and returns them as a bytestring. Reads and returns *m* < *n* bytes when only *m* more bytes are currently available for reading from the file. In particular, returns the empty string when no more bytes are currently available from the file, typically because the file is finished.
write	write(*fd*, *s*) Writes all bytes from bytestring *s* to file descriptor *fd* and returns the number of bytes written.

The os.path Module

The `os.path` module supplies functions to analyze and transform path strings and path-like objects. The most commonly useful functions from the module are listed in Table 11-19.

Table 11-19. Frequently used functions of the `os.path` module

`abspath`	`abspath(`*`path`*`)`
	Returns a normalized absolute path string equivalent to *`path`*, just like (in the case where *`path`* is the name of a file in the current directory):
	`os.path.normpath(os.path.join(os.getcwd(),` *`path`*`))`
	For example, `os.path.abspath(os.curdir)` is the same as `os.getcwd()`.

`basename`	`basename(`*`path`*`)` Returns the base name part of *`path`*, just like `os.path.split(`*`path`*`)[1]`. For example, `os.path.basename('b/c/d.e')` returns `'d.e'`.
`commonpath`	`commonpath(`*`list`*`)` Accepts a sequence of strings or path-like objects, and returns the longest common subpath. Unlike `commonprefix`, only returns a valid path; raises `ValueError` if *list* is empty, contains a mixture of absolute and relative paths, or contains paths on different drives.
`common prefix`	`commonprefix(`*`list`*`)` Accepts a list of strings or pathlike objects and returns the longest string that is a prefix of all items in the list, or `'.'` if *`list`* is empty. For example, `os.path.commonprefix(['foobar', 'foolish'])` returns `'foo'`. May return an invalid path; see `commonpath` if you want to avoid this.
`dirname`	`dirname(`*`path`*`)` Returns the directory part of *`path`*, just like `os.path.split(`*`path`*`)[0]`. For example, `os.path.dirname('b/c/d.e')` returns `'b/c'`.
`exists, lexists`	`exists(`*`path`*`), lexists(`*`path`*`)` `exists` returns **`True`** when *`path`* names an existing file or directory (*`path`* may also be an open file descriptor or path-like object); otherwise, returns **`False`**. In other words, `os.path.exists(`*`x`*`)` is the same as `os.access(`*`x`*`, os.F_OK)`. `lexists` is the same, but also returns **`True`** when *`path`* names an existing symbolic link that indicates a nonexistent file or directory (sometimes known as a *broken symlink*), while `exists` returns **`False`** in such cases. Both return **`False`** for paths containing characters or bytes that are not representable at the OS level.

expandvars, expanduser	`expandvars(path)`, `expanduser(path)`
	Returns a copy of string or path-like object *path*, where each substring of the form `$name` or `${name}` (and `%name%` on Windows only) is replaced with the value of environment variable *name*. For example, if environment variable HOME is set to `/u/alex`, the following code:
	`import os`
	`print(os.path.expandvars('$HOME/foo/'))`
	emits `/u/alex/foo/`.
	`os.path.expanduser` expands a leading `~` or `~user`, if any, to the path of the home directory of the current user.

getatime, getctime, getmtime, getsize	`getatime(path)`, `getctime(path)`, `getmtime(path)`, `getsize(path)` Each of these functions calls `os.stat(path)` and returns an attribute from the result: respectively, `st_atime`, `st_ctime`, `st_mtime`, and `st_size`. See Table 11-17 for more details about these attributes.
isabs	`isabs(path)` Returns **True** when *path* is absolute. (A path is absolute when it starts with a (back)slash (`/` or `\`), or, on some non-Unix-like platforms, such as Windows, with a drive designator followed by `os.sep`.) Otherwise, `isabs` returns **False**.
isdir	`isdir(path)` Returns **True** when *path* names an existing directory (`isdir` follows symlinks, so `isdir` and `islink` may both return **True**); otherwise, returns **False**.
isfile	`isfile(path)` Returns **True** when *path* names an existing regular file (`isfile` follows symlinks, so `islink` may also be **True**); otherwise, returns **False**.
islink	`islink(path)` Returns **True** when *path* names a symbolic link; otherwise, returns **False**.
ismount	`ismount(path)` Returns **True** when *path* names a mount point; otherwise, returns **False**.

join	`join(path, *paths)`
	Returns a string that joins the arguments (strings or path-like objects) with the appropriate path separator for the current platform. For example, on Unix, exactly one slash character `/` separates adjacent path components. If any argument is an absolute path, `join` ignores previous arguments. For example:
	`print(os.path.join('a/b', 'c/d', 'e/f'))`
	`# on Unix prints: a/b/c/d/e/f`
	`print(os.path.join('a/b', '/c/d', 'e/f'))`
	`# on Unix prints: /c/d/e/f`
	The second call to `os.path.join` ignores its first argument `'a/b'`, since its second argument `'/c/d'` is an absolute path.

normcase	`normcase(path)` Returns a copy of *path* with case normalized for the current platform. On case-sensitive filesystems (typical in Unix-like systems), *path* is returned unchanged. On case-insensitive filesystems (typical in Windows), it lowercases the string. On Windows, `normcase` also converts each `/` to a `\\`.

`normpath`	`normpath(*path*)` Returns a normalized pathname equivalent to *`path`*, removing redundant separators and path-navigation aspects. For example, on Unix, `normpath` returns `'a/b'` when *`path`* is any of `'a//b'`, `'a/./b'`, or `'a/c/../b'`. `normpath` makes path separators appropriate for the current platform. For example, on Windows, separators become `\\`.
`realpath`	`realpath(*path*, *, strict=**False**)` Returns the actual path of the specified file or directory or path-like object, resolving symlinks along the way. **3.10+** Set `strict=**True**` to raise `OSError` when *`path`* doesn't exist, or when there is a loop of symlinks.
`relpath`	`relpath(*path*, start=os.curdir)` Returns a path to the file or directory *`path`* (a `str` or path-like object) relative to directory `start`.
`samefile`	`samefile(*path1*, *path2*)` Returns **`True`** if both arguments (strings or path-like objects) refer to the same file or directory.
`sameopen file`	`sameopenfile(*fd1*, *fd2*)` Returns **`True`** if both arguments (file descriptors) refer to the same file or directory.
`samestat`	`samestat(*stat1*, *stat2*)` Returns **`True`** if both arguments (instances of `os.stat_result`, typically results of `os.stat` calls) refer to the same file or directory.
`split`	`split(*path*)` Returns a pair of strings `(*dir*, *base*)` such that `join(*dir*, *base*)` equals *`path`*. *`base`* is the last component and never contains a path separator. When *`path`* ends in a separator, *`base`* is `''`. *`dir`* is the leading part of *`path`*, up to the last separator excluded. For example, `os.path.split('a/b/c/d')` returns `('a/b/c', 'd')`.
`splitdrive`	`splitdrive(*path*)` Returns a pair of strings `(*drv*, *pth*)` such that *`drv+pth`* equals *`path`*. *`drv`* is a drive specification, or `''`; it is always `''` on platforms without drive specifications, e.g. Unix-like systems. On Windows, `os.path.splitdrive('c:d/e')` returns `('c:'`, `'d/e')`.
`splitext`	`splitext(*path*)` Returns a pair `(*root*, *ext*)` such that *`root+ext`* equals *`path`*. *`ext`* is either `''` or starts with a `'.'` and has no other `'.'` or path separator. For example, `os.path.splitext('a.a/b.c.d')` returns the pair `('a.a/b.c'`, `'.d')`.

OSError Exceptions

When a request to the operating system fails, `os` raises an exception, an instance of `OSError`. `os` also exposes the built-in exception class `OSError` with the synonym `os.error`. Instances of `OSError` expose three useful attributes, detailed in Table 11-20.

Table 11-20. Attributes of `OSError` instances

`errno`	The numeric error code of the operating system error

filename	The name of the file on which the operation failed (file-related functions only)
strerror	A string that briefly describes the error

OSError has subclasses to specify what the problem was, as discussed in "OSError subclasses" on page 208.

os functions can also raise other standard exceptions, such as TypeError or ValueError, when called with invalid argument types or values, so that they didn't even attempt the underlying operating system functionality.

The errno Module

The errno module supplies dozens of symbolic names for error code numbers. Use errno to handle possible system errors selectively, based on error codes; this will enhance your program's portability and readability. However, a selective **except** with the appropriate OSError subclass often works better than errno. For example, to handle "file not found" errors, while propagating all other kinds of errors, you could use:

```
import errno
try:
    os.some_os_function_or_other()
except FileNotFoundError as err:
    print(f'Warning: file {err.filename!r} not found; continuing')
except OSError as oserr:
    print(f'Error {errno.errorcode[oserr.errno]}; continuing')
```

errno supplies a dictionary named errorcode: the keys are error code numbers, and the corresponding values are the error names, strings such as 'ENOENT'. Displaying errno.errorcode[err.errno] as part of the explanation behind some OSError instance's err can often make the diagnosis clearer and more understandable to readers who specialize in the specific platform.

The pathlib Module

The pathlib module provides an object-oriented approach to filesystem paths, pulling together a variety of methods for handling paths and files as objects, not as strings (unlike os.path). For most use cases, pathlib.Path will provide everything you'll need. On rare occasions, you'll want to instantiate a platform-specific path, or a "pure" path that doesn't interact with the operating system; see the online docs if you need such advanced functionality. The most commonly useful functions of pathlib.Path are listed in Table 11-21, with examples for a pathlib.Path object *p*. On Windows, pathlib.Path objects are returned as WindowsPath; on Unix, as PosixPath, as shown in the examples in Table 11-21. (For clarity, we are simply importing pathlib rather than using the more common and idiomatic **from** pathlib **import** Path.)

pathlib Methods Return Path Objects, Not Strings

Keep in mind that `pathlib` methods typically return a path object, not a string, so results of similar methods in `os` and `os.path` do *not* test as being identical.

Table 11-21. Commonly used methods of `pathlib.Path`

<table>
<tr><td>chmod,
lchmod</td><td>p.chmod(mode, follow_symlinks=True),
p.lchmod(mode)
chmod changes the file mode and permissions, like os.chmod (see Table 11-16). On Unix platforms, 3.10+ set follow_symlinks=False to change permissions on the symbolic link rather than its target, or use lchmod. See the online docs for more information on chmod settings.lchmod is like chmod but, when p points to a symbolic link, changes the symbolic link rather than its target. Equivalent to pathlib.Path.chmod(follow_symlinks=False).</td></tr>
<tr><td>cwd</td><td>pathlib.Path.cwd()
Returns the current working directory as a path object.</td></tr>
<tr><td>exists</td><td>p.exists()
Returns True when p names an existing file or directory (or a symbolic link pointing to an existing file or directory); otherwise, returns False.</td></tr>
<tr><td>expanduser</td><td>p.expanduser()
Returns a new path object with a leading ~ expanded to the path of the home directory of the current user, or ~user expanded to the path of the home directory of the given user. See also home later in this table.</td></tr>
<tr><td>glob,
rglob</td><td>p.glob(pattern),
p.rglob(pattern)
Yield all matching files in directory p in arbitrary order. pattern may include ** to allow recursive globbing in p or any subdirectory; rglob always performs recursive globbing in p and all subdirectories, as if pattern started with '**/'. For example:
<pre>
>>> sorted(td.glob('*'))
[WindowsPath('tempdir/bar'),
WindowsPath('tempdir/foo')]
>>> sorted(td.glob('**/*'))
[WindowsPath('tempdir/bar'),
WindowsPath('tempdir/bar/baz'),
WindowsPath('tempdir/bar/boo'),
WindowsPath('tempdir/foo')]
>>> sorted(td.glob('*/**/*')) # expanding at 2nd+ level
[WindowsPath('tempdir/bar/baz'),
WindowsPath('tempdir/bar/boo')]
>>> sorted(td.rglob('*')) # just like glob('**/*')
[WindowsPath('tempdir/bar'),
WindowsPath('tempdir/bar/baz'),
WindowsPath('tempdir/bar/boo'),
WindowsPath('tempdir/foo')]
</pre></td></tr>
</table>

`hardlink_to`	*p*`.hardlink_to(`*`target`*`)` **3.10+** Makes *p* a hard link to the same file as *`target`*. Replaces the deprecated `link_to` **3.8+**, `-3.10` Note: the order of arguments for `link_to` was like `os.link`, described in Table 11-16; for `hardlink_to`, like for `symlink_to` later in this table, it's the reverse.
`home`	`pathlib.Path.home()` Returns the user's home directory as a path object.
`is_dir`	*p*`.is_dir()` Returns **`True`** when *p* names an existing directory (or a symbolic link to a directory); otherwise, returns **`False`**.
`is_file`	*p*`.is_file()` Returns **`True`** when *p* names an existing file (or a symbolic link to a file); otherwise, returns **`False`**.
`is_mount`	*p*`.is_mount()` Returns **`True`** when *p* is a *mount point* (a point in a filesystem where a different filesystem has been mounted); otherwise, returns **`False`**. See the online docs for details. Not implemented on Windows.
`is_symlink`	*p*`.is_symlink()` Returns **`True`** when *p* names an existing symbolic link; otherwise, returns **`False`**.
`iterdir`	*p*`.iterdir()` Yields path objects for the contents of directory *p* (`'.'` and `'..'` not included) in arbitrary order. Raises `NotADirectoryError` when *p* is not a directory. May produce unexpected results if you remove a file from *p*, or add a file to *p*, after you create the iterator and before you're done using it.

`mkdir`	*p*`.mkdir(mode=0o777, parents=`**`False`**`, exist_ok=`**`False`**`)`
	Creates a new directory at the path. Use `mode` to set file mode and access flags. Pass `parents=`**`True`** to create any missing parents as needed. Pass `exist_ok=`**`True`** to ignore `FileExistsError` exceptions. For example:
	`>>> td=pathlib.Path('tempdir/')`
	`>>> td.mkdir(exist_ok=True)`
	`>>> td.is_dir()`
	`True`
	See the online docs for thorough coverage.

`open`	*p*`.open(mode='r', buffering=-1, encoding=`**`None`**`, errors=`**`None`**`, newline=`**`None`**`)` Opens the file pointed to by the path, like the built-in `open(`*`p`*`)` (with other args the same).
`read_bytes`	*p*`.read_bytes()` Returns the binary contents of *p* as a `bytes` object.
`read_text`	*p*`.read_text(encoding=`**`None`**`, errors=`**`None`**`)` Returns the decoded contents of *p* as a string.
`readlink`	*p*`.readlink()` **3.9+** Returns the path to which a symbolic link points.

rename	*p*.rename(*target*) Renames *p* to *target* and **3.8+** returns a new Path instance pointing to *target*. *target* may be a string, or an absolute or relative path; however, relative paths are interpreted relative to the *current* working directory, *not* the directory of *p*. On Unix, when *target* is an existing file or empty directory, rename replaces it silently when the user has permission; on Windows, rename raises FileExistsError.

replace	*p*.replace(*target*)
	Like *p*.rename(*target*), but, on any platform, when *target* is an existing file (or, except on Windows, an empty directory), replace replaces it silently when the user has permission. For example:
	`>>> p.read_text()`
	`'spam'`
	`>>> t.read_text()`
	`'and eggs'`
	`>>> p.replace(t)`
	`WindowsPath('C:/Users/annar/testfile.txt')`
	`>>> t.read_text()`
	`'spam'`
	`>>> p.read_text()`
	`Traceback (most recent call last):`
	`...`
	`FileNotFoundError: [Errno 2] No such file...`

resolve	*p*.resolve(strict=**False**)
	Returns a new absolute path object with symbolic links resolved; eliminates any '..' components. Set strict=**True** to raise exceptions: FileNotFoundError when the path does not exist, or RuntimeError when it encounters an infinite loop. For example, on the temporary directory created in the mkdir example earlier in this table:
	`>>> td.resolve()`
	`PosixPath('/Users/annar/tempdir')`

rmdir	*p*.rmdir() Removes directory *p*. Raises OSError if *p* is not empty.
samefile	*p*.samefile(*target*) Returns **True** when *p* and *target* indicate the same file; otherwise, returns **False**. *target* may be a string or a path object.
stat	p.stat(*, follow_symlinks=**True**) Returns information about the path object, including permissions and size; see os.stat in Table 11-16 for return values. **3.10+** To stat a symbolic link itself, rather than its target, pass follow_symlinks=**False**.
symlink_to	*p*.symlink_to(*target*, target_is_directory=**False**) Makes *p* a symbolic link to *target*. On Windows, you must set target_is_directory=**True** if *target* is a directory. (POSIX ignores this argument.) (On Windows 10+, like os.symlink, requires Developer Mode permissions; see the online docs for details.) Note: the order of arguments is the reverse of the order for os.link and os.symlink, described in Table 11-16.

`touch`	`p.touch(mode=0o666, exist_ok=True)`
	Like `touch` on Unix, creates an empty file at the given path. When the file already exists, updates the modification time to the current time if `exist_ok=True`; if `exist_ok=False`, raises `FileExistsError`. For example:
	`>>> d`
	`WindowsPath('C:/Users/annar/Documents')`
	`>>> f = d / 'testfile.txt'`
	`>>> f.is_file()`
	`False`
	`>>> f.touch()`
	`>>> f.is_file()`
	`True`

`unlink`	`p.unlink(missing_ok=False)` Removes file or symbolic link *p*. (Use `rmdir` for directories, as described earlier in this table.) **3.8+** Pass `missing_ok=True` to ignore `FileExistsError`.
`write_bytes`	`p.write_bytes(data)` Opens (or, if need be, creates) the file pointed to in bytes mode, writes *data* to it, then closes the file. Overwrites the file if it already exists.
`write_text`	`p.write_text(data, encoding=None, errors=None, newline=None)` Opens (or, if need be, creates) the file pointed to in text mode, writes *data* to it, then closes the file. Overwrites the file if it already exists. **3.10+** When `newline` is **None** (the default), translates any `'\n'` to the system default line separator; when `'\r'` or `'\r\n'`, translates `'\n'` to the given string; when `''` or `'\n'`, no translation takes place.

`pathlib.Path` objects also support the attributes listed in Table 11-22 to access the various component parts of the path string. Note that some attributes are strings, while others are `Path` objects. (For brevity, OS-specific types such as `PosixPath` or `WindowsPath` are shown simply using the abstract `Path` class.)

Table 11-22. Attributes of an instance p of `pathlib.Path`

Attribute	Description	Value for Unix path Path('/usr/bin/ python')	Value for Windows path Path(r'c:\Python3\ python.exe')
`anchor`	Combination of `drive` and `root`	`'/'`	`'c:\\'`
`drive`	Drive letter of *p*	`''`	`'c:'`
`name`	End component of *p*	`'python'`	`'python.exe'`
`parent`	Parent directory of *p*	`Path('/usr/bin')`	`Path('c:\Python3')`
`parents`	Ancestor directories of *p*	`(Path('/usr/bin'), Path('/usr'), Path('/'))`	`(Path('c:\Python3'), Path('c:\\'))`

Attribute	Description	Value for Unix path Path('/usr/bin/ python')	Value for Windows path Path(r'c:\Python3\python.exe')
`parts`	Tuple of all components of *p*	`('/', 'usr', 'bin', 'python')`	`('c:\\', 'Python3', 'python.exe')`
`root`	Root directory of *p*	`'/'`	`'\\'`
`stem`	Name of *p*, minus suffix	`'python'`	`'python'`
`suffix`	Ending suffix of *p*	`''`	`'.exe'`
`suffixes`	List of all suffixes of *p*, as delimited by `'.'` characters	`[]`	`['.exe']`

The online documentation includes more examples for paths with additional components, such as filesystem and UNC shares.

`pathlib.Path` objects also support the `'/'` operator, an excellent alternative to `os.path.join` or `Path.joinpath` from the `Path` module. See the example code in the description of `Path.touch` in Table 11-21.

The stat Module

The function `os.stat` (covered in Table 11-16) returns instances of `stat_result`, whose item indices, attribute names, and meaning are also covered there. The `stat` module supplies attributes with names like those of `stat_result`'s attributes in uppercase, and corresponding values that are the corresponding item indices.

The more interesting contents of the `stat` module are functions to examine the `st_mode` attribute of a `stat_result` instance and determine the kind of file. `os.path` also supplies functions for such tasks, which operate directly on the file's *`path`*. The functions supplied by `stat`, shown in Table 11-23, are faster than `os`'s when you perform several tests on the same file: they require only one `os.stat` system call at the start of a series of tests to obtain the file's `st_mode`, while the functions in `os.path` implicitly ask the operating system for the same information at each test. Each function returns **`True`** when *`mode`* denotes a file of the given kind; otherwise, it returns **`False`**.

Table 11-23. `stat` module functions for examining `st_mode`

`S_ISBLK`	`S_ISBLK(`*`mode`*`)` Indicates whether *`mode`* denotes a special-device file of the block kind
`S_ISCHR`	`S_ISCHR(`*`mode`*`)` Indicates whether *`mode`* denotes a special-device file of the character kind
`S_ISDIR`	`S_ISDIR(`*`mode`*`)` Indicates whether *`mode`* denotes a directory

`S_ISFIFO`	`S_ISFIFO(`*`mode`*`)` Indicates whether *`mode`* denotes a FIFO (also known as a "named pipe")
`S_ISLNK`	`S_ISLNK(`*`mode`*`)` Indicates whether *`mode`* denotes a symbolic link
`S_ISREG`	`S_ISREG(`*`mode`*`)` Indicates whether *`mode`* denotes a normal file (not a directory, special device-file, etc.)
`S_ISSOCK`	`S_ISSOCK(`*`mode`*`)` Indicates whether *`mode`* denotes a Unix-domain socket

Several of these functions are meaningful only on Unix-like systems, since other platforms do not keep special files such as devices and sockets in the same namespace as regular files; Unix-like systems do.

The `stat` module also supplies two functions that extract relevant parts of a file's *`mode`* (*`x`*`.st_mode`, for some result *`x`* of function `os.stat`), listed in Table 11-24.

Table 11-24. `stat` module functions for extracting bits from mode

`S_IFMT`	`S_IFMT(`*`mode`*`)` Returns those bits of *`mode`* that describe the kind of file (i.e., the bits that are examined by the functions `S_ISDIR`, `S_ISREG`, etc.)
`S_IMODE`	`S_IMODE(`*`mode`*`)` Returns those bits of *`mode`* that can be set by the function `os.chmod` (i.e., the permission bits and, on Unix-like platforms, a few other special bits such as the `set-user-id` flag)

The `stat` module supplies a utility function, `stat.filemode(`*`mode`*`)`, that converts a file's mode to a human readable string of the form `'-rwxrwxrwx'`.

The filecmp Module

The `filecmp` module supplies a few functions that are useful for comparing files and directories, listed in Table 11-25.

Table 11-25. Useful functions of the `filecmp` module

`clear_cache`	`clear_cache()` Clears the `filecmp` cache, which may be useful in quick file comparisons.
`cmp`	`cmp(`*`f1`*`, `*`f2`*`, shallow=`**`True`**`)` Compares the files (or `pathlib.Paths`) identified by path strings *`f1`* and *`f2`*. If the files are deemed to be equal, `cmp` returns **`True`**; otherwise, it returns **`False`**. If `shallow` is **`True`**, files are deemed to be equal if their `stat` tuples are equal. When `shallow` is **`False`**, `cmp` reads and compares the contents of files whose `stat` tuples are equal.

`cmpfiles`	`cmpfiles(`*`dir1`*`,` *`dir2`*`,` *`common`*`, shallow=`**`True`**`)` Loops on the sequence *`common`*. Each item of *`common`* is a string that names a file present in both directories *`dir1`* and *`dir2`*. `cmpfiles` returns a tuple whose items are three lists of strings: `(`*`equal`*`,` *`diff`*`,` and *`errs`*`)`. *`equal`* is the list of names of files that are equal in both directories, *`diff`* is the list of names of files that differ between directories, and *`errs`* is the list of names of files that it could not compare (because they do not exist in both directories, or there is no permission to read one or both of them). The argument `shallow` is the same as for `cmp`.

The `filecmp` module also supplies the class `dircmp`. The constructor for this class has the signature:

`dircmp`	**`class`** `dircmp(`*`dir1`*`,` *`dir2`*`, ignore=`**`None`**`, hide=`**`None`**`)` Creates a new directory-comparison instance object comparing directories *`dir1`* and *`dir2`*, ignoring names listed in `ignore` and hiding names listed in `hide` (defaulting to `'.'` and `'..'` when `hide=`**`None`**). The default value for `ignore` is supplied by the `DEFAULT_IGNORE` attribute of the `filecmp` module; at the time of this writing it is `['RCS', 'CVS', 'tags', '.git', '.hg', '.bzr', '_darcs', '__pycache__']`. Files in the directories are compared like with `filecmp.cmp` with `shallow=`**`True`**.

A `dircmp` instance *d* supplies three methods, detailed in Table 11-26.

Table 11-26. Methods supplied by a `dircmp` instance d

`report`	`report_full_closure()` Outputs to `sys.stdout` a comparison between *`dir1`* and *`dir2`* and all their common subdirectories, recursively
`report_full_closure`	`report_full_closure()` Outputs to `sys.stdout` a comparison between *`dir1`* and *`dir2`* and all their common subdirectories, recursively
`report_partial_closure`	`report_partial_closure()` Outputs to `sys.stdout` a comparison between *`dir1`* and *`dir2`* and their common immediate subdirectories

In addition, *d* supplies several attributes, covered in Table 11-27. These attributes are computed "just in time" (i.e., only if and when needed, thanks to a `__getattr__` special method) so that using a `dircmp` instance incurs no unnecessary overhead.

Table 11-27. Attributes supplied by a `dircmp` instance d

`common`	Files and subdirectories that are in both *`dir1`* and *`dir2`*
`common_dirs`	Subdirectories that are in both *`dir1`* and *`dir2`*
`common_files`	Files that are in both *`dir1`* and *`dir2`*

`common_funny`	Names that are in both *`dir1`* and *`dir2`* for which `os.stat` reports an error or returns different kinds for the versions in the two directories
`diff_files`	Files that are in both *`dir1`* and *`dir2`* but with different contents
`funny_files`	Files that are in both *`dir1`* and *`dir2`* but could not be compared
`left_list`	Files and subdirectories that are in *`dir1`*
`left_only`	Files and subdirectories that are in *`dir1`* and not in *`dir2`*
`right_list`	Files and subdirectories that are in *`dir2`*
`right_only`	Files and subdirectories that are in *`dir2`* and not in *`dir1`*
`same_files`	Files that are in both *`dir1`* and *`dir2`* with the same contents
`subdirs`	A dictionary whose keys are the strings in `common_dirs`; the corresponding values are instances of `dircmp` (or **3.10+** of the same `dircmp` subclass as *d*) for each subdirectory

The fnmatch Module

The `fnmatch` module (an abbreviation for *filename match*) matches filename strings or paths with patterns that resemble the ones used by Unix shells, as listed in Table 11-28.

Table 11-28. `fnmatch` pattern matching conventions

Pattern	Matches
`*`	Any sequence of characters
`?`	Any single character
`[`*`chars`*`]`	Any one of the characters in *`chars`*
`[!`*`chars`*`]`	Any one character not among those in *`chars`*

`fnmatch` does *not* follow other conventions of Unix shell pattern matching, such as treating a slash (`/`) or a leading dot (`.`) specially. It also does not allow escaping special characters: rather, to match a special character, enclose it in brackets. For example, to match a filename that's a single close bracket, use `'[]]'`.

The `fnmatch` module supplies the functions listed in Table 11-29.

Table 11-29. Functions of the `fnmatch` module

`filter`	`filter(`*`names`*`, `*`pattern`*`)` Returns the list of items of *`names`* (a sequence of strings) that match *`pattern`*.

fnmatch	fnmatch(*filename*, *pattern*) Returns **True** when string *filename* matches *pattern*; otherwise, returns **False**. The match is case sensitive when the platform is (for example, typical Unix-like systems), and otherwise (for example, on Windows) case insensitive; beware of that, if you're dealing with a filesystem whose case-sensitivity doesn't match your platform (for example, macOS is Unix-like; however, its typical filesystems are case insensitive).
fnmatchcase	fnmatchcase(*filename*, *pattern*) Returns **True** when string *filename* matches *pattern*; otherwise, returns **False**. The match is always case-sensitive on any platform.
translate	translate(*pattern*) Returns the regular expression pattern (as covered in "Pattern String Syntax" on page 306) equivalent to the fnmatch pattern *pattern*.

The glob Module

The glob module lists (in arbitrary order) the pathnames of files that match a *path pattern*, using the same rules as fnmatch; in addition, it treats a leading dot (.), separator (/), and ** specially, like Unix shells do. Table 11-30 lists some useful functions provided by the glob module.

Table 11-30. Functions of the glob module

escape	escape(*pathname*) Escapes all special characters ('?', '*', and '['), so you can match an arbitrary literal string that may contain special characters.
glob	glob(*pathname*, *, root_dir=**None**, dir_fd=**None**, recursive=**False**) Returns the list of pathnames of files that match the pattern *pathname*. root_dir (if not **None**) is a string or path-like object specifying the root directory for searching (this works like changing the current directory before calling glob). If *pathname* is relative, the paths returned are relative to root_dir. To search paths relative to directory descriptors, pass dir_fd instead. Optionally pass named argument recursive=**True** to have path component ** recursively match zero or more levels of subdirectories.
iglob	iglob(*pathname*, *, root_dir=**None**, dir_fd=**None**, recursive=**False**) Like glob, but returns an iterator yielding one relevant pathname at a time.

The shutil Module

The shutil module (an abbreviation for *shell utilities*) supplies functions to copy and move files, and to remove an entire directory tree. On some Unix platforms, most of the functions support the optional keyword-only argument follow_symlinks, defaulting to **True**. When follow_symlinks=**True**, if a path indicates a symbolic link, the function follows it to reach an actual file or directory; when **False**, the function operates on the symbolic link itself. Table 11-31 lists the functions provided by the shutil module.

Table 11-31. Functions of the `shutil` module

`copy`	`copy(`*`src`*`, `*`dst`*`)` Copies the contents of the file named by *`src`*, which must exist, and creates or overwrites the file *`dst`* (*`src`* and *`dst`* are strings or instances of `pathlib.Path`). If *`dst`* is a directory, the target is a file with the same base name as *`src`*, but located in *`dst`*. `copy` also copies permission bits, but not last access and modification times. Returns the path to the destination file it has copied to.
`copy2`	`copy2(`*`src`*`, `*`dst`*`)` Like `copy`, but also copies last access time and modification time.
`copyfile`	`copyfile(`*`src`*`, `*`dst`*`)` Copies just the contents (not permission bits, nor last access and modification times) of the file named by *`src`*, creating or overwriting the file named by *`dst`*.
`copyfileobj`	`copyfileobj(`*`fsrc`*`, `*`fdst`*`, bufsize=16384)` Copies all bytes from file object *`fsrc`*, which must be open for reading, to file object *`fdst`*, which must be open for writing. Copies up to `bufsize` bytes at a time if *`bufsize`* is greater than `0`. File objects are covered in "The io Module" on page 322.
`copymode`	`copymode(`*`src`*`, `*`dst`*`)` Copies permission bits of the file or directory named by *`src`* to the file or directory named by *`dst`*. Both *`src`* and *`dst`* must exist. Does not change *`dst`*'s contents, nor its status as being a file or a directory.
`copystat`	`copystat(`*`src`*`, `*`dst`*`)` Copies permission bits and times of last access and modification of the file or directory named by *`src`* to the file or directory named by *`dst`*. Both *`src`* and *`dst`* must exist. Does not change *`dst`*'s contents, nor its status as being a file or a directory.
`copytree`	`copytree(`*`src`*`, `*`dst`*`, symlinks=`**`False`**`, ignore=`**`None`**`, copy_function=copy2, ignore_dangling_symlinks=`**`False`**`, dirs_exist_ok=`**`False`**`)` Copies the directory tree rooted at the directory named by *`src`* into the destination directory named by *`dst`*. *`dst`* must not already exist: `copytree` creates it (as well as creating any missing parent directories). `copytree` copies each file using the function `copy2`, by default; you can optionally pass a different file-copy function as named argument `copy_function`. If any exceptions occur during the copy process, `copytree` will record them internally and continue, raising `Error` at the end containing the list of all the recorded exceptions. When `symlinks` is **`True`**, `copytree` creates symbolic links in the new tree when it finds symbolic links in the source tree. When `symlinks` is **`False`**, `copytree` follows each symbolic link it finds and copies the linked-to file with the link's name, recording an exception if the linked file does not exist (if `ignore_dangling_symlinks=`**`True`**, this exception is ignored). On platforms that do not have the concept of a symbolic link, `copytree` ignores the argument `symlinks`.

File and Text Operations

`copytree` *(cont.)*	When `ignore` is not **`None`**, it must be a callable accepting two arguments (a directory path and a list of the immediate children of the directory) and returning a list of the children to be ignored in the copy process. If present, `ignore` is often the result of a call to `shutil.ignore_patterns`. For example, this code:
	`import shutil`
	`ignore = shutil.ignore_patterns('.*', '*.bak')`
	`shutil.copytree('src', 'dst', ignore=ignore)`
	copies the tree rooted at directory `src` into a new tree rooted at directory `dst`, ignoring any file or subdirectory whose name starts with a dot and any file or subdirectory whose name ends with *.bak*.
	By default, `copytree` will record a `FileExistsError` exception if a target directory already exists. **3.8+** You can set `dirs_exist_ok` to **`True`** to allow `copytree` to write into existing directories found in the copying process (and potentially overwrite their contents).

`ignore_patterns`	`ignore_patterns(*patterns)` Returns a callable picking out files and subdirectories matching *`patterns`*, like those used in the `fnmatch` module (see "The fnmatch Module" on page 365). The result is suitable for passing as the `ignore` argument to the `copytree` function.
`move`	`move(src, dst, copy_function=copy2)` Moves the file or directory named by *`src`* to that named by *`dst`*. `move` first tries using `os.rename`. Then, if that fails (because *`src`* and *`dst`* are on separate filesystems, or because *`dst`* already exists), `move` copies *`src`* to *`dst`* (using `copy2` for a file or `copytree` for a directory by default; you can optionally pass a file-copy function other than `copy2` as the named argument `copy_function`), then removes *`src`* (using `os.unlink` for a file, `rmtree` for a directory).
`rmtree`	`rmtree(path, ignore_errors=False, onerror=None)` Removes the directory tree rooted at *`path`*. When `ignore_errors` is **`True`**, `rmtree` ignores errors. When `ignore_errors` is **`False`** and `onerror` is **`None`**, errors raise exceptions. When `onerror` is not **`None`**, it must be callable with three parameters: *`func`*, *`path`*, and *`ex`*. *`func`* is the function raising the exception (`os.remove` or `os.rmdir`), *`path`* is the path passed to *`func`*, and *`ex`* is the tuple of information `sys.exc_info` returns. When `onerror` raises an exception, `rmtree` terminates, and the exception propagates.

Beyond offering functions that are directly useful, the source file *shutil.py* in the Python stdlib is an excellent example of how to use many of the `os` functions.

Text Input and Output

Python presents non-GUI text input and output streams to Python programs as file objects, so you can use the methods of file objects (covered in "Attributes and Methods of File Objects" on page 325) to operate on these streams.

Standard Output and Standard Error

The sys module (covered in "The sys Module" on page 259) has the attributes stdout and stderr, which are writable file objects. Unless you are using shell redirection or pipes, these streams connect to the "terminal" running your script. Nowadays, actual terminals are very rare: a so-called terminal is generally a screen window that supports text I/O.

The distinction between sys.stdout and sys.stderr is a matter of convention. sys.stdout, known as *standard output*, is where your program emits results. sys.stderr, known as *standard error*, is where output such as error, status, or progress messages should go. Separating program output from status and error messages helps you use shell redirection effectively. Python respects this convention, using sys.stderr for its own errors and warnings.

The print Function

Programs that output results to standard output often need to write to sys.stdout. Python's print function (covered in Table 8-2) can be a rich, convenient alternative to sys.stdout.write. print is fine for the informal output used during development to help you debug your code, but for production output, you may need more control of formatting than print affords. For example, you may need to control spacing, field widths, the number of decimal places for floating-point values, and so on. If so, you can prepare the output as an f-string (covered in "String Formatting" on page 287), then output the string, usually with the write method of the appropriate file object. (You can pass formatted strings to print, but print may add spaces and newlines; the write method adds nothing at all, so it's easier for you to control what exactly gets output.)

If you need to direct output to a file *f* that is open for writing, just calling *f*.write is often best, while print(..., file=*f*) is sometimes a handy alternative. To repeatedly direct the output from print calls to a certain file, you can temporarily change the value of sys.stdout. The following example is a general-purpose redirection function usable for such a temporary change; in the presence of multitasking, make sure to also add a lock in order to avoid any contention (see also the contextlib.redirect_stdout decorator described in Table 6-1):

```
def redirect(func: Callable, *a, **k) -> (str, Any):
    """redirect(func, *a, **k) -> (func's results, return value)
    func is a callable emitting results to standard output.
    redirect captures the results as a str and returns a pair
    (output string, return value).
    """
    import sys, io
    save_out = sys.stdout
    sys.stdout = io.StringIO()
    try:
        retval = func(*args, **kwds)
        return sys.stdout.getvalue(), retval
```

```
    finally:
        sys.stdout.close()
        sys.stdout = save_out
```

Standard Input

In addition to `stdout` and `stderr`, the `sys` module provides the `stdin` attribute, which is a readable file object. When you need a line of text from the user, you can call the built-in function `input` (covered in Table 8-2), optionally with a string argument to use as a prompt.

When the input you need is not a string (for example, when you need a number), use `input` to obtain a string from the user, then other built-ins, such as `int`, `float`, or `ast.literal_eval`, to turn the string into the number you need. To evaluate an expression or string from an untrusted source, we recommend using the function `literal_eval` from the standard library module `ast` (as covered in the online docs). `ast.literal_eval(`*`astring`*`)` returns a valid Python value (such as an `int`, a `float`, or a `list`) for the given literal *`astring`* when it can (**3.10+** stripping any leading spaces and tabs from string inputs), or else raises a `SyntaxError` or `ValueError` exception; it never has any side effects. To ensure complete safety, *`astring`* cannot contain any operator or any nonkeyword identifier; however, `+` and `-` may be accepted as positive or negative signs on numbers, rather than as operators. For example:

```
import ast
print(ast.literal_eval('23'))     # prints 23
print(ast.literal_eval('  23'))   # prints 23 (3.10++)
print(ast.literal_eval('[2,-3]')) # prints [2, -3]
print(ast.literal_eval('2+3'))    # raises ValueError
print(ast.literal_eval('2+'))     # raises SyntaxError
```

eval Can Be Dangerous

Don't use `eval` on arbitrary, unsanitized user inputs: a nasty (or well-meaning but careless) user can breach security or otherwise cause damage this way. There is no effective defense —just avoid using `eval` (and `exec`) on input from sources you do not fully trust.

The getpass Module

Very occasionally, you may want the user to input a line of text in such a way that somebody looking at the screen cannot see what the user is typing. This may occur when you're asking the user for a password, for example. The `getpass` module provides a function for this, as well as one to get the current user's username (see Table 11-32).

Table 11-32. Functions of the `getpass` module

`getpass`	`getpass(prompt='Password: ')` Like `input` (covered in Table 8-2), except that the text the user inputs is not echoed to the screen as the user is typing, and the default `prompt` is different from `input`'s.
`getuser`	`getuser()` Returns the current user's username. `getuser` tries to get the username as the value of one of the environment variables LOGNAME, USER, LNAME, or USERNAME, in that order. If none of these variables are in `os.environ`, `getuser` asks the operating system.

Richer-Text I/O

The text I/O modules covered so far supply basic text I/O functionality on all platform terminals. Most platforms also offer enhanced text I/O features, such as responding to single keypresses (not just entire lines), printing text in any terminal row and column position, and enhancing the text with background and foreground colors and font effects like bold, italic, and underline. For this kind of functionality you'll need to consider a third-party library. We focus here on the `readline` module, then take a quick look at a few console I/O options, including `mscvrt`, with a brief mention of `curses`, `rich`, and `colorama`, which we do not cover further.

The readline Module

The `readline` module wraps the GNU Readline Library, which lets the user edit text lines during interactive input and recall previous lines for editing and re-entry. Readline comes preinstalled on many Unix-like platforms, and it's available online. On Windows, you can install and use the third-party module `pyreadline`.

When `readline` is available, Python uses it for all line-oriented input, such as `input`. The interactive Python interpreter always tries to load `readline` to enable line editing and recall for interactive sessions. Some `readline` functions control advanced functionality: particularly *history*, for recalling lines entered in previous sessions; and *completion*, for context-sensitive completion of the word being entered. (See the Python `readline` docs for complete details on configuration commands.) You can access the module's functionality using the functions in Table 11-33.

Table 11-33. Functions of the `readline` module

`add_history`	`add_history(s, /)` Adds string *`s`* as a line at the end of the history buffer. To temporarily disable `add_history`, call `set_auto_history(False)`, which will disable `add_history` for this session only (it won't persist across sessions); `set_auto_history` is **`True`** by default.
`append_history_file`	`append_history_file(n, filename='~/.history', /)` Appends the last *n* items to existing file *`filename`*.

`clear_history`	`clear_history()` Clears the history buffer.
`get_completer`	`get_completer()` Returns the current completer function (as last set by `set_completer`), or **None** if no completer function is set.
`get_history_length`	`get_history_length()` Returns the number of lines of history to be saved to the history file. When the result is less than `0`, all lines in the history are to be saved.

`parse_and_bind`	`parse_and_bind(`*`readline_cmd`*`, /)`
	Gives `readline` a configuration command. To let the user hit Tab to request completion, call `parse_and_bind('tab: complete')`. See the `readline` documentation for other useful values of the string *`readline_cmd`*.
	A good completion function is in the standard library module `rlcompleter`. In the interactive interpreter (or in the startup file executed at the start of interactive sessions, covered in "Environment Variables" on page 22), enter:
	`import readline, rlcompleter`
	`readline.parse_and_bind('tab: complete')`
	For the rest of this interactive session, you can hit the Tab key during line editing and get completion for global names and object attributes.

`read_history_file`	`read_history_file(`*`filename`*`='~/.history', /)` Loads history lines from the text file at path *`filename`*.
`read_init_file`	`read_init_file(`*`filename`*`=`**`None`**`, /)` Makes `readline` load a text file: each line is a configuration command. When *`filename`* is **None**, loads the same file as the last time.
`set_completer`	`set_completer(`*`func`*`, /)` Sets the completion function. When *`func`* is **None** or omitted, `readline` disables completion. Otherwise, when the user types a partial word *`start`*, then presses the Tab key, `readline` calls *`func`*`(`*`start`*`, `*`i`*`)`, with *`i`* initially `0`. *`func`* returns the *`i`*th possible word starting with *`start`*, or **None** when there are no more. `readline` loops, calling *`func`* with *`i`* set to `0`, `1`, `2`, etc., until *`func`* returns **None**.
`set_history_length`	`set_history_length(`*`x`*`, /)` Sets the number of lines of history that are to be saved to the history file. When *`x`* is less than `0`, all lines in the history are to be saved.
`write_history_file`	`write_history_file(`*`filename`*`='~/.history')` Saves history lines to the text file whose name or path is *`filename`*, overwriting any existing file.

Console I/O

As mentioned previously, "terminals" today are usually text windows on a graphical screen. You may also, in theory, use a true terminal, or (perhaps a tad less theoretically, but these days not by much) the console (main screen) of a personal computer in text mode. All such "terminals" in use today offer advanced text I/O functionality, accessed in platform-dependent ways. The low-level `curses` package works on Unix-like platforms. For a cross-platform (Windows, Unix, macOS) solution, you may use the third-party package `rich`; in addition to its excellent online docs, there are online tutorials to help you get started. To output colored text on the terminal, see `colorama`, available on PyPI. `msvcrt`, introduced next, provides some low-level (Windows only) functions.

curses

The classic Unix approach to enhanced terminal I/O is named `curses`, for obscure historical reasons.[4] The Python package `curses` lets you exert detailed control if required. We don't cover `curses` in this book; for more information, see A.M. Kuchling's and Eric Raymond's online tutorial "Curses Programming with Python".

The msvcrt module

The Windows-only `msvcrt` module (which you may need to install with `pip`) supplies a few low-level functions that let Python programs access proprietary extras supplied by the Microsoft Visual C++ runtime library *msvcrt.dll*. For example, the functions listed in Table 11-34 let you read user input character by character rather than reading a full line at a time.

4 "Curses" does describe well the typical utterances of programmers faced with this complicated, low-level approach.

Table 11-34. Some useful functions of the `msvcrt` module

`getch`, `getche`	`getch()`, `getche()`
	Reads and returns a single-character bytes from keyboard input, and if necessary blocks until one is available (i.e., a key is pressed). `getche` echoes the character to screen (if printable), while `getch` does not. When the user presses a special key (arrows, function keys, etc.), it's seen as two characters: first a `chr(0)` or `chr(224)`, then a second character that, together with the first one, defines the special key the user pressed. This means that the program must call `getch` or `getche` twice to read these key presses. To find out what `getch` returns for any key, run the following small script on a Windows machine:
	`import msvcrt`
	`print("press z to exit, or any other key "`
	`      "to see the key's code:")`
	`while True:`
	`    c = msvcrt.getch()`
	`    if c == b'z':`
	`        break`
	`    print(f'{ord(c)} ({c!r})')`

`kbhit`	`kbhit()` Returns **`True`** when a character is available for reading (`getch`, when called, returns immediately); otherwise, returns **`False`** (`getch`, when called, waits).
`ungetch`	`ungetch(`*`c`*`)` "Ungets" character *c*; the next call to `getch` or `getche` returns *c*. It's an error to call `ungetch` twice without intervening calls to `getch` or `getche`.

Internationalization

Many programs present some information to users as text. Such text should be understandable and acceptable to users in different locales. For example, in some countries and cultures, the date "March 7" can be concisely expressed as "3/7." Elsewhere, "3/7" indicates "July 3," and the string that means "March 7" is "7/3." In Python, such cultural conventions are handled with the help of the standard library module `locale`.

Similarly, a greeting might be expressed in one natural language by the string "Benvenuti," while in another language the string to use is "Welcome." In Python, such translations are handled with the help of the stdlib module `gettext`.

Both kinds of issues are commonly addressed under the umbrella term *internationalization* (often abbreviated *i18n*, as there are 18 letters between *i* and *n* in the full spelling in English)—a misnomer, since the same issues apply not just between nations, but also to different languages or cultures within a single nation.[5]

5 I18n includes the process of "localization," or adapting international software to local language and cultural conventions.

The locale Module

Python's support for cultural conventions imitates that of C, slightly simplified. A program operates in an environment of cultural conventions known as a *locale*. The locale setting permeates the program and is typically set at program startup. The locale is not thread-specific, and the `locale` module is not thread-safe. In a multithreaded program, set the program's locale in the main thread; i.e., set it before starting secondary threads.

Limitations of locale

`locale` is only useful for process-wide settings. If your application needs to handle multiple locales at the same time in a single process—whether in threads or asynchronously—`locale` is not the answer due to its process-wide nature. Consider, instead, alternatives such as PyICU, mentioned in "More Internationalization Resources" on page 382.

If a program does not call `locale.setlocale`, the *C locale* (so called due to Python's C language roots) is used; it's similar, but not identical, to the US English locale. Alternatively, a program can find out and accept the user's default locale. In this case, the `locale` module interacts with the operating system (via the environment or in other system-dependent ways) to try to find the user's preferred locale. Finally, a program can set a specific locale, presumably determining which locale to set on the basis of user interaction or via persistent configuration settings.

Locale setting is normally performed across the board for all relevant categories of cultural conventions. This common wide-spectrum setting is denoted by the constant attribute `LC_ALL` of the `locale` module. However, the cultural conventions handled by `locale` are grouped into categories, and, in some rare cases, a program can choose to mix and match categories to build up a synthetic composite locale. The categories are identified by the attributes listed in Table 11-35.

Table 11-35. Constant attributes of the `locale` module

LC_COLLATE	String sorting; affects functions strcoll and strxfrm in locale
LC_CTYPE	Character types; affects aspects of module string (and string methods) that have to do with lowercase and uppercase letters
LC_MESSAGES	Messages; may affect messages displayed by the operating system (for example, messages displayed by function os.strerror and module gettext)
LC_MONETARY	Formatting of currency values; affects functions localeconv and currency in locale
LC_NUMERIC	Formatting of numbers; affects functions atoi, atof, format_string, locale conv, and str in locale, as well as the number separators used in format strings (e.g., f-strings and str.format) when format character 'n' is used
LC_TIME	Formatting of times and dates; affects the function time.strftime

The settings of some categories (denoted by LC_CTYPE, LC_MESSAGES, and LC_TIME) affect behavior in other modules (string, os, gettext, and time, as indicated). Other categories (denoted by LC_COLLATE, LC_MONETARY, and LC_NUMERIC) affect only some functions of locale itself (plus string formatting in the case of LC_NUMERIC).

The locale module supplies the functions listed in Table 11-36 to query, change, and manipulate locales, as well as functions that implement the cultural conventions of locale categories LC_COLLATE, LC_MONETARY, and LC_NUMERIC.

Table 11-36. Useful functions of the `locale` module

atof	atof(*s*) Parses the string *s* into a floating-point number using the current LC_NUMERIC setting.
atoi	atoi(*s*) Parses the string *s* into an integer number using the current LC_NUMERIC setting.
cur rency	currency(*data*, grouping=**False**, international=**False**) Returns the string or number *data* with a currency symbol, and, if grouping is **True**, uses the monetary thousands separator and grouping. When international is **True**, uses int_curr_symbol and int_frac_digits, described later in this table.

format_ string	`format_string(fmt, num, grouping=False, monetary=False)`
	Returns the string obtained by formatting *num* according to the format string *fmt* and the LC_NUMERIC or LC_MONETARY settings. Except for cultural convention issues, the result is like old-style *fmt* % *num* string formatting, covered in "Legacy String Formatting with %" on page 297. If *num* is an instance of a number type and *fmt* is *%d* or *%f*, set grouping to **True** to group digits in the result string according to the LC_NUMERIC setting. If monetary is **True**, the string is formatted with mon_decimal_point, and *grouping* uses mon_thousands_sep and mon_grouping instead of the ones supplied by LC_NUMERIC (see localeconv later in this table for more information on these). For example:
	<pre>>>> locale.setlocale(locale.LC_NUMERIC,
	... 'en_us')
	'en_us'
	>>> n=1000*1000
	>>> locale.format_string('%d', n)
	'1000000'
	>>> locale.setlocale(locale.LC_MONETARY,
	... 'it_it')
	'it_it'
	>>> locale.format_string('%f', n)
	'1000000.000000' # uses decimal_point
	>>> locale.format_string('%f', n,
	... monetary=True)
	'1000000,000000' # uses mon_decimal_point
	>>> locale.format_string('%0.2f', n,
	... grouping=True)
	'1,000,000.00' # separators & decimal from
	                   # LC_NUMERIC
	>>> locale.format_string('%0.2f', n,
	... grouping=True,
	... monetary=True)
	'1.000.000,00' # separators & decimal from
	                   # LC_MONETARY</pre>In this example, since the numeric locale is set to US English, when the argument grouping is **True**, format_string groups digits by threes with commas and uses a dot (.) for the decimal point. However, the monetary locale is set to Italian, so when the argument monetary is **True**, format_string uses a comma (,) for the decimal point and grouping uses a dot (.) for the thousands separator. Usually, the syntaxes for monetary and nonmonetary numbers are equal within any given locale.

get default locale	`getdefaultlocale(envvars=('LANGUAGE', 'LC_ALL', 'LC_TYPE', 'LANG'))` Checks the environment variables whose names are specified by envvars, in order. The first one found in the environment determines the default locale. getdefaultlocale returns a pair of strings (*lang*, *encoding*) compliant with RFC 1766 (except for the 'C' locale), such as ('en_US', 'UTF-8'). Each item of the pair may be **None** if gedefaultlocale is unable to discover what value the item should have.
get locale	`getlocale(category=LC_CTYPE)` Returns a pair of strings (*lang*, *encoding*) with the current setting for the given category. The category cannot be LC_ALL.

locale conv `localeconv()`

Returns a `dict` *d* with the cultural conventions specified by categories `LC_NUMERIC` and `LC_MONETARY` of the current locale. While `LC_NUMERIC` is best used indirectly, via other functions of `locale`, the details of `LC_MONETARY` are accessible only through *d*. Currency formatting is different for local and international use. For example, the `'$'` symbol is for *local* use only; it is ambiguous in *international* use, since the same symbol is used for many currencies called "dollars" (US, Canadian, Australian, Hong Kong, etc.). In international use, therefore, the symbol for US currency is the unambiguous string `'USD'`. The function temporarily sets the `LC_CTYPE` locale to the `LC_NUMERIC` locale, or the `LC_MONETARY` locale if the locales are different and the numeric or monetary strings are non-ASCII. This temporary change affects all threads. The keys into *d* to use for currency formatting are the following strings:

`'currency_symbol'`
: Currency symbol to use locally

`'frac_digits'`
: Number of fractional digits to use locally

`'int_curr_symbol'`
: Currency symbol to use internationally

`'int_frac_digits'`
: Number of fractional digits to use internationally

`'mon_decimal_point'`
: String to use as the "decimal point" (aka *radix point*) for monetary values

`'mon_grouping'`
: List of digit-grouping numbers for monetary values

`'mon_thousands_sep'`
: String to use as digit-groups separator for monetary values

`'negative_sign'`, `'positive_sign'`
: Strings to use as the sign symbol for negative (positive) monetary values

`'n_cs_precedes'`, `'p_cs_precedes'`
: **`True`** when the currency symbol comes before negative (positive) monetary values

`'n_sep_by_space'`, `'p_sep_by_space'`
: **`True`** when a space goes between the sign and negative (positive) monetary values

`'n_sign_posn'`, `'p_sign_posn'`
: See Table 11-37 for a list of numberic codes for formating negative (positive) monetary values.

`CHAR_MAX`
: Indicates that the current locale does not specify any convention for this formatting

locale conv *(cont.)*	*d*['mon_grouping'] is a list of numbers of digits to group when formatting a monetary value (but take care: in some locales, *d*['mon_grouping'] may be an empty list). When *d*['mon_grouping'][-1] is 0, there is no further grouping beyond the indicated numbers of digits. When *d*['mon_grouping'][-1] is locale.CHAR_MAX, grouping continues indefinitely, as if *d*['mon_grouping'][-2] were endlessly repeated. locale.CHAR_MAX is a constant used as the value for all entries in *d* for which the current locale does not specify any convention.
local ize	localize(*normstr*, grouping=**False**, monetary=**False**) Returns a formatted string following LC_NUMERIC (or LC_MONETARY, when monetary is **True**) settings from normalized numeric string *normstr*.
normal ize	normalize(*localename*) Returns a string, suitable as an argument to setlocale, that is the normalized form for *localename*. When normalize cannot normalize the string *localename*, it returns *localename* unchanged.
reset locale	resetlocale(category=LC_ALL) Sets the locale for category to the default given by getdefaultlocale.
set locale	setlocale(*category*, locale=**None**) Sets the locale for *category* to locale, if not **None**, and returns the setting (the existing one when locale is **None**; otherwise, the new one). locale can be a string, or a pair (*lang*, *encoding*). *lang* is normally a language code based on ISO 639 two-letter codes ('en' is English, 'nl' is Dutch, and so on). When locale is the empty string '', setlocale sets the user's default locale. To see valid locales, view the locale.locale_alias dictionary.
str	str(*num*) Like locale.format_string('%f', *num*).
strcoll	strcoll(*str1*, *str2*) Respecting the LC_COLLATE setting, returns -1 when *str1* comes before *str2* in collation, 1 when *str2* comes before *str1*, and 0 when the two strings are equivalent for collation purposes.

strxfrm	strxfrm(*s*)
	Returns a string *sx* such that Python's built-in comparisons of two or more strings so transformed is like calling locale.strcoll on the originals. strxfrm lets you easily use the key argument for sorts and comparisons needing locale-conformant string comparisons. For example,
	`def locale_sort_inplace(list_of_strings):`
	`    list_of_strings.sort(key=locale.strxfrm)`

Table 11-37. Numeric codes to format monetary values

0	The value and the currency symbol are placed inside parentheses
1	The sign is placed before the value and the currency symbol
2	The sign is placed after the value and the currency symbol
3	The sign is placed immediately before the value
4	The sign is placed immediately after the value

The gettext Module

A key issue in internationalization is the ability to use text in different natural languages, a task known as *localization* (sometimes *l10n*). Python supports localization via the standard library module `gettext`, inspired by GNU `gettext`. The `gettext` module is optionally able to use the latter's infrastructure and APIs, but also offers a simpler, higher-level approach, so you don't need to install or study GNU `gettext` to use Python's `gettext` effectively.

For full coverage of `gettext` from a different perspective, see the online docs.

Using gettext for localization

`gettext` does not deal with automatic translation between natural languages. Rather, it helps you extract, organize, and access the text messages that your program uses. Pass each string literal subject to translation, also known as a *message*, to a function named `_` (underscore) rather than using it directly. `gettext` normally installs a function named `_` in the `builtins` module. To ensure that your program runs with or without `gettext`, conditionally define a do-nothing function, named `_`, that just returns its argument unchanged. Then you can safely use `_('message')` wherever you would normally use a literal `'message'` that should be translated, if feasible. The following example shows how to start a module for conditional use of `gettext`:

```
try:
    _
except NameError:
    def _(s): return s
def greet():
    print(_('Hello world'))
```

If some other module has installed `gettext` before you run this example code, the function `greet` outputs a properly localized greeting. Otherwise, `greet` outputs the string `'Hello world'` unchanged.

Edit your source, decorating message literals with the function `_`. Then use any of various tools to extract messages into a text file (normally named *messages.pot*) and distribute the file to the people who translate messages into the various natural languages your application must support. Python supplies a script *pygettext.py* (in the directory *Tools/i18n* in the Python source distribution) to perform message extraction on your Python sources.

Each translator edits *messages.pot* to produce a text file of translated messages, with extension *.po*. Compile the *.po* files into binary files with extension *.mo*, suitable for fast searching, using any of various tools. Python supplies a script *msgfmt.py* (also in *Tools/i18n*) for this purpose. Finally, install each *.mo* file with a suitable name in a suitable directory.

Conventions about which directories and names are suitable differ among platforms and applications. `gettext`'s default is subdirectory *share/locale/<lang>/LC_MES-*

SAGES/ of directory *sys.prefix*, where *<lang>* is the language's code (two letters). Each file is named *<name>.mo*, where *<name>* is the name of your application or package.

Once you have prepared and installed your *.mo* files, you normally execute, at the time your application starts up, some code such as the following:

```
import os, gettext
os.environ.setdefault('LANG', 'en')  # application-default language
gettext.install('your_application_name')
```

This ensures that calls such as `_('message')` return the appropriate translated strings. You can choose different ways to access `gettext` functionality in your program; for example, if you also need to localize C-coded extensions, or to switch between languages during a run. Another important consideration is whether you're localizing a whole application, or just a package that is distributed separately.

Essential gettext functions

`gettext` supplies many functions. The most often used functions are listed in Table 11-38; see the online docs for a complete list.

Table 11-38. Useful functions of the `gettext` module

`install`	`install(`*`domain`*`, localedir=`**`None`**`, names=`**`None`**`)` Installs in Python's built-in namespace a function named _ to perform translations given in the file *<lang>/LC_MESSAGES/<domain>.mo* in the directory `localedir`, with language code *<lang>* as per `getdefaultlocale`. When `localedir` is **None**, `install` uses the directory `os.path.join(sys.prefix, 'share', 'locale')`. When `names` is provided, it must be a sequence containing the names of functions you want to install in the `builtins` namespace in addition to _. Supported names are `'gettext'`, `'lgettext'`, `'lngettext'`, `'ngettext'`, **3.8+** `'npgettext'`, and **3.8+** `'pgettext'`.
`translation`	`translation(`*`domain`*`, localedir=`**`None`**`, languages=`**`None`**`, class_=`**`None`**`, fallback=`**`False`**`)` Searches for a *.mo* file, like the `install` function; if it finds multiple files, `translation` uses later files as fallbacks for earlier ones. Set `fallback` to **`True`** to return a `NullTranslations` instance; otherwise, the function raises `OSError` when it doesn't find any *.mo* file. When `languages` is **None**, `translation` looks in the environment for the *<lang>* to use, like `install`. It examines, in order, the environment variables LANGUAGE, LC_ALL, LC_MESSAGES, and LANG, and splits the first nonempty one on `':'` to give a list of language names (for example, it splits `'de:en'` into `['de', 'en']`). When not **None**, `languages` must be a list of one or more language names (for example, `['de', 'en']`). `translation` uses the first language name in the list for which it finds a *.mo* file.

`translation` *(cont.)*	`translation` returns an instance object of a translation class (by default, `GNUTranslations`; if present, the class's constructor must take a single file object argument) that supplies the methods `gettext` (to translate a `str`) and `install` (to install `gettext` under the name _ in Python's `builtins` namespace). `translation` offers more detailed control than `install`, which is like `translation(`*`domain, localedir`*`).install(`*`unicode`*`)`. With `translation`, you can localize a single package without affecting the built-in namespace, by binding the name _ on a per-module basis—for example, with: `_ = translation(domain).ugettext`

More Internationalization Resources

Internationalization is a very large topic. For a general introduction, see Wikipedia. One of the best packages of code and information for internationalization, which the authors happily recommend, is ICU, embedding also the Unicode Consortium's Common Locale Data Repository (CLDR) database of locale conventions and code to access the CLDR. To use ICU in Python, install the third-party package PyICU.

12
Persistence and Databases

Python supports several ways of persisting data. One way, *serialization*, views data as a collection of Python objects. These objects can be *serialized* (saved) to a byte stream, and later *deserialized* back (loaded and re-created) from the byte stream. *Object persistence* relies on serialization, adding features such as object naming. This chapter covers the Python modules that support serialization and object persistence.

Another way to make data persistent is to store it in a database (DB). One simple category of DBs are files that use *keyed access* to enable selective reading and updating of parts of the data. This chapter covers Python standard library modules that support several variations of such a file format, known as *DBM*.

A *relational DB management system* (RDBMS), such as PostgreSQL or Oracle, offers a more powerful approach to storing, searching, and retrieving persistent data. Relational DBs rely on dialects of Structured Query Language (SQL) to create and alter a DB's schema, insert and update data in the DB, and query the DB with search criteria. (This book does not provide reference material on SQL; for this purpose we recommend O'Reilly's *SQL in a Nutshell*, by Kevin Kline, Regina Obe, and Leo Hsu.) Unfortunately, despite the existence of SQL standards, no two RDBMSs implement exactly the same SQL dialect.

The Python standard library does not come with an RDBMS interface. However, many third-party modules let your Python programs access a specific RDBMS. Such modules mostly follow the Python Database API 2.0 standard, also known as the *DBAPI*. This chapter covers the DBAPI standard and mentions a few of the most popular third-party modules that implement it.

A DBAPI module that is particularly handy (because it comes with every standard installation of Python) is `sqlite3`, which wraps SQLite. SQLite, "a self-contained, server-less, zero-configuration, transactional SQL DB engine," is the most widely deployed relational DB engine in the world. We cover `sqlite3` in "SQLite" on page 405.

Besides relational DBs, and the simpler approaches covered in this chapter, there exist several NoSQL DBs, such as Redis and MongoDB, each with Python interfaces. We do not cover advanced nonrelational DBs in this book.

Serialization

Python supplies several modules to *serialize* (save) Python objects to various kinds of byte streams and *deserialize* (load and re-create) Python objects back from streams. Serialization is also known as *marshaling*, which means formatting for *data interchange*.

Serialization approaches span a vast range, from the low-level, Python-version-specific `marshal` and language-independent JSON (both limited to elementary data types) to the richer but Python-specific `pickle` and cross-language formats such as XML, YAML, protocol buffers, and MessagePack.

In this section, we cover Python's `csv`, `json`, `pickle`, and `shelve` modules. We cover XML in Chapter 23. `marshal` is too low-level to use in applications; should you need to maintain old code using it, refer to the online docs. As for protocol buffers, MessagePack, YAML, and other data-interchange/serialization approaches (each with specific advantages and weaknesses), we cannot cover everything in this book; we recommend studying them via the resources available on the web.

The csv Module

While the CSV (standing for *comma-separated values*[1]) format isn't usually considered a form of serialization, it is a widely used and convenient interchange format for tabular data. Since much data is tabular, CSV data is used a lot, despite some lack of agreement on exactly how it should be represented in files. To overcome this issue, the `csv` module provides a number of *dialects* (specifications of the way particular sources encode CSV data) and lets you define your own dialects. You can register additional dialects and list the available dialects by calling the `csv.list_dialects` function. For further information on dialects, consult the module's documentation.

csv functions and classes

The `csv` module exposes the functions and classes detailed in Table 12-1. It provides two kinds of readers and writers to let you handle CSV data rows in Python as either lists or dictionaries.

1 In fact, "CSV" is something of a misnomer, since some dialects use tabs or other characters rather than commas as the field separator. It might be easier to think of them as "delimiter-separated values."

Table 12-1. Functions and classes of the csv module

`reader`	`reader(`*`csvfile`*`, dialect='excel', **`*`kw`*`)` Creates and returns a reader object *r*. *csvfile* can be any iterable object yielding text rows as `str`s (usually a list of lines or a file opened with `newline=''`[a]); `dialect` is the name of a registered dialect. To modify the dialect, add named arguments: their values override dialect fields of the same name. Iterating over *r* yields a sequence of lists, each containing the elements from one row of *csvfile*.
`writer`	`writer(`*`csvfile`*`, dialect='excel', **`*`kw`*`)` Creates and returns a writer object *w*. *csvfile* is an object with a `write` method (if a file, open it with `newline=''`); *dialect* is the name of a registered dialect. To modify the dialect, add named arguments: their values override dialect fields of the same name. *w*`.writerow` accepts a sequence of values and writes their CSV representation as a row to *csvfile*. *w*`.writerows` accepts an iterable of such sequences and calls *w*`.writerow` on each. You are responsible for closing *csvfile*.
`Dict Reader`	`DictReader(`*`csvfile`*`, fieldnames=`**`None`**`, restkey=`**`None`**`, restval=`**`None`**`, dialect='excel', *`*`args`*`, **`*`kw`*`)` Creates and returns an object *r* that iterates over *csvfile* to generate an iterable of dictionaries (-3.8 `OrderedDict`s), one for each row. When the `fieldnames` argument is given, it is used to name the fields in *csvfile*; otherwise, the field names are taken from the first row of *csvfile*. If a row contains more columns than field names, the extra values are saved as a list with the key `restkey`. If there are insufficient values in any row, then those column values will be set to `restval`. `dialect`, *kw*, and *args* are passed to the underlying reader object.
`Dict Writer`	`DictWriter(`*`csvfile`*`, `*`fieldnames`*`, restval='', extrasaction='raise', dialect='excel', *`*`args`*`, **`*`kwds`*`)` Creates and returns an object *w* whose `writerow` and `writerows` methods take a dictionary or iterable of dictionaries and write them using the *csvfile*'s `write` method. *fieldnames* is a sequence of `str`s, the keys to the dictionaries. *restval* is the value used to fill up a dictionary that's missing some keys. `extrasaction` specifies what to do when a dictionary has extra keys not listed in *fieldnames*: when `'raise'`, the default, the function raises `ValueError` in such cases; when `'ignore'`, the function ignores such errors. `dialect`, *kw*, and *args* are passed to the underlying reader object. You are responsible for closing *csvfile* (usually a file opened with `newline=''`).

[a] Opening a file with `newline=''` allows the csv module to use its own newline processing and correctly handle dialects in which text fields may contain newlines.

A csv example

Here is a simple example using `csv` to read color data from a list of strings:

```
import csv

color_data = '''\
color,r,g,b
red,255,0,0
green,0,255,0
blue,0,0,255
cyan,0,255,255
magenta,255,0,255
yellow,255,255,0
'''.splitlines()

colors = {row['color']:
          row for row in csv.DictReader(color_data)}

print(colors['red'])
# prints: {'color': 'red', 'r': '255', 'g': '0', 'b': '0'}
```

Note that the integer values are read as strings. `csv` does not do any data conversion; that needs to be done by your program code with the `dict`s returned from `DictReader`.

The json Module

The standard library's `json` module supports serialization for Python's native data types (`tuple`, `list`, `dict`, `int`, `str`, etc.). To serialize instances of your own custom classes, you should implement corresponding classes inheriting from `JSONEncoder` and `JSONDecoder`.

json functions

The `json` module supplies four key functions, detailed in Table 12-2.

Table 12-2. Functions of the `json` module

`dump`	`dump(`*`value`*`, `*`fileobj`*`, skipkeys=`**`False`**`, ensure_ascii=`**`True`**`, check_circular=`**`True`**`, allow_nan=`**`True`**`, cls=JSONEncoder, indent=`**`None`**`, separators=(', ', ': '), default=`**`None`**`, sort_keys=`**`False`**`, **`*`kw`*`)` Writes the JSON serialization of object *`value`* to file-like object *`fileobj`*, which must be opened for writing in text mode, via calls to *`fileobj`*`.write`. Each call to *`fileobj`*`.write` passes a text string as an argument. When `skipkeys` is **`True`** (by default, it's **`False`**), `dict` keys that are not scalars (i.e., are not of types `bool`, `float`, `int`, `str`, or **`None`**) raise an exception. In any case, keys that *are* scalars are turned into strings (e.g., **`None`** becomes `'null'`): JSON only allows strings as keys in its mappings.

`dump` *(cont.)*	When `ensure_ascii` is **`True`** (the default), all non-ASCII characters in the output are escaped; when it's **`False`**, they're output as is. When `check_circular` is **`True`** (the default), containers in *`value`* are checked for circular references and a `ValueError` exception is raised if any are found; when it's **`False`**, the check is skipped, and many different exceptions can get raised as a result (even a crash is possible). When `allow_nan` is **`True`** (the default), float scalars `nan`, `inf`, and `-inf` are output as their respective JavaScript equivalents, `NaN`, `Infinity`, and `-Infinity`; when it's **`False`**, the presence of such scalars raises a `ValueError` exception. You can optionally pass `cls` in order to use a customized subclass of `JSONEncoder` (such advanced customization is rarely needed, and we don't cover it in this book); in this case, `**`*`kw`* gets passed in the call to `cls` that instantiates it. By default, encoding uses the `JSONEncoder` class directly. When `indent` is an `int > 0`, `dump` "pretty-prints" the output by prepending that many spaces to each array element and object member; when it's an `int <= 0`, `dump` just inserts `\n` characters. When `indent` is **`None`** (the default), `dump` uses the most compact representation. `indent` can also be a `str`—for example, `'\t'`—and in that case `dump` uses that string for indenting. `separators` must be a tuple with two items, respectively the strings used to separate items and to separate keys from values. You can explicitly pass `separators=(',', ':')` to ensure `dump` inserts no whitespace. You can optionally pass `default` in order to transform some otherwise nonserializable objects into serializable ones. `default` is a function called with a single argument that's a nonserializable object, and it must return a serializable object or raise `ValueError` (by default, the presence of nonserializable objects raises `ValueError`). When `sort_keys` is **`True`** (by default, it's **`False`**), mappings are output in sorted order of their keys; when **`False`**, they're output in whatever is their natural order of iteration (nowadays, for most mappings, insertion order).
`dumps`	`dumps(`*`value`*`, skipkeys=`**`False`**`, ensure_ascii=`**`True`**`, check_circular=`**`True`**`, allow_nan=`**`True`**`, cls=JSONEncoder, indent=`**`None`**`, separators=(', ', ': '), default=`**`None`**`, sort_keys=`**`False`**`, **`*`kw`*`)` Returns the string that's the JSON serialization of object *`value`*—that is, the string that `dump` would write to its file object argument. All arguments to `dumps` have exactly the same meaning as the arguments to `dump`.

JSON Serializes Just One Object per File

JSON is not what is known as a *framed format*: this means it is *not* possible to call `dump` more than once in order to serialize multiple objects into the same file, nor to later call `load` more than once to deserialize the objects, as would be possible, for example, with `pickle` (discussed in the following section). So, technically, JSON serializes just one object per file. However, that one object can be a `list` or `dict` that can contain as many items as you wish.

`load`	`load(`*`fileobj`*`, encoding='utf-8', cls=JSONDecoder, object_hook=`**`None`**`, parse_float=float, parse_int=int, parse_constant=`**`None`**`, object_pairs_hook=`**`None`**`, **`*`kw`*`)` Creates and returns the object *v* previously serialized into file-like object *`fileobj`*, which must be opened for reading in text mode, getting *`fileobj`*'s contents via a call to *`fileobj`*`.read`. The call to *`fileobj`*`.read` must return a text (Unicode) string. The functions `load` and `dump` are complementary. In other words, a single call to `load(`*`f`*`)` deserializes the same value previously serialized when *f*'s contents were created by a single call to `dump(`*`v`*`, `*`f`*`)` (possibly with some alterations: e.g., all dictionary keys are turned into strings). You can optionally pass `cls` in order to use a customized subclass of `JSONDecoder` (such advanced customization is rarely needed, and we don't cover it in this book); in this case, `**`*`kw`* gets passed in the call to `cls`, which instantiates it. By default, decoding uses the `JSONDecoder` class directly. You can optionally pass `object_hook` or `object_pairs_hook` (if you pass both, `object_hook` is ignored and only `object_pairs_hook` is used), a function that lets you implement custom decoders. When you pass `object_hook` but not `object_pairs_hook`, each time an object is decoded into a `dict`, `load` calls `object_hook` with the `dict` as the only argument, and uses `object_hook`'s return value instead of that `dict`. When you pass `object_pairs_hook`, each time an object is decoded, `load` calls `object_pairs_hook` with, as the only argument, a list of the pairs of `(`*`key`*`, `*`value`*`)` items of the object, in the order in which they are present in the input, and uses `object_pairs_hooks`'s return value. This lets you perform specialized decoding that potentially depends on the order of `(`*`key`*`, `*`value`*`)` pairs in the input. `parse_float`, `parse_int`, and `parse_constant` are functions called with a single argument: a `str` representing a `float`, an `int`, or one of the three special constants `'NaN'`, `'Infinity'`, or `'-Infinity'`. `load` calls the appropriate function each time it identifies in the input a `str` representing a number, and uses the function's return value. By default, `parse_float` is the built-in function `float`, `parse_int` is `int`, and `parse_constant` is a function that returns one of the three special float scalars `nan`, `inf`, or `-inf`, as appropriate. For example, you could pass `parse_float=decimal.Decimal` to ensure that all numbers in the result that would normally be `float`s are instead decimals (covered in "The decimal Module" on page 500).
`loads`	`loads(`*`s`*`, cls=JSONDecoder, object_hook=`**`None`**`, parse_float=float, parse_int=int, parse_constant=`**`None`**`, object_pairs_hook=`**`None`**`, **`*`kw`*`)` Creates and returns the object *v* previously serialized into the string *`s`*. All arguments to `loads` have exactly the same meaning as the arguments to `load`.

A json example

Say you need to read several text files, whose names are given as your program's arguments, recording where each distinct word appears in the files. What you need to record for each word is a list of `(`*`filename`*`, `*`linenumber`*`)` pairs. The following example uses the `fileinput` module to iterate through all the files given as program arguments, and `json` to encode the lists of `(`*`filename`*`, `*`linenumber`*`)` pairs as strings and store them in a DBM-like file (as covered in "DBM Modules" on page 396). Since these lists contain tuples, each containing a string and a number, they are within json's abilities to serialize:

```
import collections, fileinput, json, dbm
word_pos = collections.defaultdict(list)
for line in fileinput.input():
    pos = fileinput.filename(), fileinput.filelineno()
    for word in line.split():
        word_pos[word].append(pos)
with dbm.open('indexfilem', 'n') as dbm_out:
    for word, word_positions in word_pos.items():
        dbm_out[word] = json.dumps(word_positions)
```

We can then use json to deserialize the data stored in the DBM-like file *indexfilem*, as in the following example:

```
import sys, json, dbm, linecache
with dbm.open('indexfilem') as dbm_in:
    for word in sys.argv[1:]:
        if word not in dbm_in:
             print(f'Word {word!r} not found in index file',
             continue
        places = json.loads(dbm_in[word])
        for fname, lineno in places:
            print(f'Word {word!r} occurs in line {lineno}'
                  f' of file {fname!r}:')
            print(linecache.getline(fname, lineno), end='')
```

The pickle Module

The pickle module supplies factory functions, named Pickler and Unpickler, to generate objects (instances of nonsubclassable types, not classes) that wrap files and supply Python-specific serialization mechanisms. Serializing and deserializing via these modules is also known as *pickling* and *unpickling*.

Serialization shares some of the issues of deep copying, covered in "The copy Module" on page 263. The pickle module deals with these issues in much the same way as the copy module does. Serialization, like deep copying, implies a recursive walk over a directed graph of references. pickle preserves the graph's shape: when the same object is encountered more than once, the object is serialized only the first time, and other occurrences of the same object serialize references to that single value. pickle also correctly serializes graphs with reference cycles. However, this means that if a mutable object *o* is serialized more than once to the same Pickler instance *p*, any changes to *o* after the first serialization of *o* to *p* are not saved.

Don't Alter Objects While Their Serialization Is Underway

For clarity, correctness, and simplicity, don't alter objects that are being serialized while serialization to a `Pickler` instance is in progress.

`pickle` can serialize with a legacy ASCII protocol or with one of several compact binary protocols. Table 12-3 lists the available protocols.

Table 12-3. `pickle` protocols

Protocol	Format	Added in Python version	Description
`0`	ASCII	1.4[a]	Human-readable format, slow to serialize/deserialize
`1`	Binary	1.5	Early binary format, superseded by protocol `2`
`2`	Binary	2.3	Improved support for later Python 2 features
`3`	Binary	3.0	(-3.8 default) Added specific support for `bytes` objects
`4`	Binary	3.4	(3.8+ default) Included support for very large objects
`5`	Binary	3.8	3.8+ Added features to support pickling as serialization for transport between processes, per PEP 574

[a] Or possibly earlier. This is the oldest version of documentation available at Python.org.

Always Pickle with Protocol 2 or Higher

Always use *at least* protocol `2`. The size and speed savings can be substantial, and binary format has basically no downside except loss of compatibility of resulting pickles with truly ancient versions of Python.

When you reload objects, `pickle` transparently recognizes and uses any protocol that the Python version you're currently using supports.

`pickle` serializes classes and functions by name, not by value.[2] `pickle` can therefore deserialize a class or function only by importing it from the same module where the class or function was found when `pickle` serialized it. In particular, `pickle` can normally serialize and deserialize classes and functions only if they are top-level names (i.e., attributes) of their respective modules. Consider the following example:

2 Consider the third-party package `dill` if you need to extend `pickle` in this and other aspects.

```python
def adder(augend):
    def inner(addend, augend=augend):
        return addend+augend
    return inner
plus5 = adder(5)
```

This code binds a closure to name `plus5` (as covered in "Nested functions and nested scopes" on page 107)—a nested function `inner` plus an appropriate outer scope. Therefore, trying to pickle `plus5` raises an `AttributeError`: a function can be pickled only when it is top-level, and the function `inner`, whose closure is bound to the name `plus5` in this code, is not top-level but rather is nested inside the function `adder`. Similar issues apply to pickling nested functions and nested classes (i.e., classes not at the top level).

pickle functions and classes

The `pickle` module exposes the functions and classes listed in Table 12-4.

Table 12-4. Functions and classes of the `pickle` module

`dump`, `dumps`	`dump(`*`value`*`, `*`fileobj`*`, protocol=`**`None`**`, bin=`**`None`**`)`, `dumps(`*`value`*`, protocol=`**`None`**`, bin=`**`None`**`)` `dumps` returns a bytestring representing the object *`value`*. `dump` writes the same string to the file-like object *`fileobj`*, which must be opened for writing. `dump(`*`v`*`, `*`f`*`)` is like *`f`*`.write(dumps(`*`v`*`))`. The `protocol` parameter can be `0` (ASCII output, the slowest and bulkiest option), or a larger `int` for various kinds of binary output (see Table 12-3). Unless `protocol` is `0`, the *`fileobj`* parameter to dump must be open for binary writing. Do not pass the `bin` parameter, which exists only for compatibility with old versions of Python.
`load`, `loads`	`load(`*`fileobj`*`)`, `loads(`*`s`*`, *, fix_imports=True, encoding="ASCII", errors="strict")` The functions `load` and `dump` are complementary. In other words, a sequence of calls to `load(`*`f`*`)` deserializes the same values previously serialized when *f*'s contents were created by a sequence of calls to `dump(`*`v`*`, `*`f`*`)`. `load` reads the right number of bytes from file-like object *`fileobj`* and creates and returns the object *v* represented by those bytes. `load` and `loads` transparently support pickles performed in any binary or ASCII protocol. If data is pickled in any binary format, the file must be open as binary for both `dump` and `load`. `load(`*`f`*`)` is like `Unpickler(`*`f`*`).load()`.

load, loads *(cont.)*	`loads` creates and returns the object *v* represented by bytestring *s*, so that for any object *v* of a supported type, *v*==`loads(dumps(`*v*`))`. If *s* is longer than `dumps(`*v*`)`, `loads` ignores the extra bytes. Optional arguments `fix_imports`, `encoding`, and `errors` are provided for handling streams generated by Python 2 code; see the `pickle.loads` documentation for further information.

Never Unpickle Untrusted Data

Unpickling from an untrusted data source is a security risk; an attacker could exploit this vulnerability to execute arbitrary code.

Pickler	`Pickler(`*fileobj*`, protocol=`**None**`, bin=`**None**`)` Creates and returns an object *p* such that calling *p*`.dump` is equivalent to calling the function `dump` with the *fileobj*, `protocol`, and `bin` arguments passed to `Pickler`. To serialize many objects to a file, `Pickler` is more convenient and faster than repeated calls to `dump`. You can subclass `pickle.Pickler` to override `Pickler` methods (particularly the method `persistent_id`) and create your own persistence framework. However, this is an advanced topic and is not covered further in this book.
Unpickler	`Unpickler(`*fileobj*`)` Creates and returns an object *u* such that calling the *u*`.load` is equivalent to calling `load` with the *fileobj* argument passed to `Unpickler`. To deserialize many objects from a file, `Unpickler` is more convenient and faster than repeated calls to the function `load`. You can subclass `pickle.Unpickler` to override `Unpickler` methods (particularly the method `persistent_load`) and create your own persistence framework. However, this is an advanced topic and is not covered further in this book.

A pickling example

The following example handles the same task as the `json` example shown earlier, but uses `pickle` instead of `json` to serialize lists of `(`*filename*`, `*linenumber*`)` pairs as strings:

```
import collections, fileinput, pickle, dbm
word_pos = collections.defaultdict(list)
for line in fileinput.input():
    pos = fileinput.filename(), fileinput.filelineno()
    for word in line.split():
        word_pos[word].append(pos)

with dbm.open('indexfilep', 'n') as dbm_out:
    for word, word_positions in word_pos.items():
        dbm_out[word] = pickle.dumps(word_positions, protocol=2)
```

We can then use `pickle` to read back the data stored to the DBM-like file *indexfilep*, as shown in the following example:

```
import sys, pickle, dbm, linecache
with dbm.open('indexfilep') as dbm_in:
```

```python
    for word in sys.argv[1:]:
        if word not in dbm_in:
            print(f'Word {word!r} not found in index file',
                  file=sys.stderr)
            continue
        places = pickle.loads(dbm_in[word])
        for fname, lineno in places:
            print(f'Word {word!r} occurs in line {lineno}'
                  f' of file {fname!r}:')
            print(linecache.getline(fname, lineno), end='')
```

Pickling instances

In order for `pickle` to reload an instance *x*, `pickle` must be able to import *x*'s class from the same module in which the class was defined when `pickle` saved the instance. Here is how `pickle` saves the state of instance object *x* of class *T* and later reloads the saved state into a new instance *y* of *T* (the first step of the reloading is always to make a new empty instance *y* of *T*, except where we explicitly say otherwise):

- When *T* supplies the method `__getstate__`, `pickle` saves the result *d* of calling `T.__getstate__(x)`.
- When *T* supplies the method `__setstate__`, *d* can be of any type, and `pickle` reloads the saved state by calling `T.__setstate__(y, d)`.
- Otherwise, *d* must be a dictionary, and `pickle` just sets `y.__dict__` = *d*.
- Otherwise, when *T* supplies the method `__getnewargs__`, and `pickle` is pickling with protocol 2 or higher, `pickle` saves the result *t* of calling `T.__getnewargs__(x)`; *t* must be a tuple.
- `pickle`, in this one case, does not start with an empty *y*, but rather creates *y* by executing *y* = `T.__new__(T, *t)`, which concludes the reloading.
- Otherwise, by default, `pickle` saves as *d* the dictionary `x.__dict__`.
- When *T* supplies the method `__setstate__`, `pickle` reloads the saved state by calling `T.__setstate__(y, d)`.
- Otherwise, `pickle` just sets `y.__dict__` = *d*.

All the items in the *d* or *t* object that `pickle` saves and reloads (normally a dictionary or tuple) must, in turn, be instances of types suitable for pickling and unpickling (aka *pickleable* objects), and the procedure just outlined may be repeated recursively, if necessary, until `pickle` reaches primitive pickleable built-in types (dictionaries, tuples, lists, sets, numbers, strings, etc.).

As mentioned in "The copy Module" on page 263, the `__getnewargs__`, `__getstate__`, and `__setstate__` special methods also control the way instance objects are copied and deep copied. If a class defines `__slots__`, and therefore its instances do not have a `__dict__` attribute, `pickle` does its best to save and restore a dictionary equivalent to the names and values of the slots. However, such a class should define `__getstate__` and `__setstate__`; otherwise, its instances may not be correctly pickleable and copied through such best-effort endeavors.

Pickling customization with the copyreg module

You can control how `pickle` serializes and deserializes objects of an arbitrary type by registering factory and reduction functions with the module `copyreg`. This is particularly, though not exclusively, useful when you define a type in a C-coded Python extension. The `copyreg` module supplies the functions listed in Table 12-5.

Table 12-5. Functions of the copyreg module

`constructor`	`constructor(`*`fcon`*`)` Adds *fcon* to the table of constructors, which lists all factory functions that `pickle` may call. *fcon* must be callable and is normally a function.
`pickle`	`pickle(`*`type`*`, `*`fred`*`, fcon=`**`None`**`)` Registers function *fred* as the *reduction function* for type *type*, where *type* must be a type object. To save an object *o* of type *type*, the module `pickle` calls *fred*`(`*o*`)` and saves the result. *fred*`(`*o*`)` must return a tuple `(fcon, `*t*`)` or `(fcon, `*t*`, `*d*`)`, where *fcon* is a constructor and *t* is a tuple. To reload *o*, `pickle` uses *o*`=fcon(*`*t*`)`. Then, when *fred* also returns a *d*, `pickle` uses *d* to restore *o*'s state (when *o* supplies `__setstate__`, *o*`.__setstate__(`*d*`)`; otherwise, *o*`.__dict__.update(`*d*`)`), as described in the previous section. If *fcon* is not **None**, `pickle` also calls `construc tor(`*fcon*`)` to register *fcon* as a constructor. `pickle` does not support pickling of code objects, but `marshal` does. Here's how you could customize pickling to support code objects by delegating the work to `marshal` thanks to `copyreg`:

```
>>> import pickle, copyreg, marshal
>>> def marsh(x):
...     return marshal.loads, (marshal.dumps(x),)
...
>>> c=compile('2+2','','eval')
>>> copyreg.pickle(type(c), marsh)
>>> s=pickle.dumps(c, 2)
>>> cc=pickle.loads(s)
>>> print(eval(cc))
4
```

Using marshal Makes Your Code Python Version Dependent

Be careful when using `marshal` in your code, as the preceding example does. `marshal`'s serialization isn't guaranteed to be stable across versions, so using `marshal` means that programs written in other versions of Python may be unable to load the objects your program has serialized.

The shelve Module

The `shelve` module orchestrates the modules `pickle`, `io`, and `dbm` (and its underlying modules for access to DBM-like archive files, as discussed in the following section) in order to provide a simple, lightweight persistence mechanism.

`shelve` supplies a function, `open`, that is polymorphic to `dbm.open`. The mapping *s* returned by `shelve.open` is less limited, however, than the mapping *a* returned by `dbm.open`. *a*'s keys and values must be strings.[3] *s*'s keys must also be strings, but *s*'s values may be of any pickleable types. `pickle` customizations (`copyreg`, `__getnewargs__`, `__getstate__`, and `__setstate__`) also apply to `shelve`, as `shelve` delegates serialization to `pickle`. Keys and values are stored as bytes. When strings are used, they are implicitly converted to the default encoding before being stored.

Persistence and Databases

Beware of a subtle trap when you use `shelve` with mutable objects: when you operate on a mutable object held in a shelf, the changes aren't stored back unless you assign the changed object back to the same index. For example:

```
import shelve
s = shelve.open('data')
s['akey'] = list(range(4))
print(s['akey'])            # prints: [0, 1, 2, 3]
s['akey'].append(9)         # trying direct mutation
print(s['akey'])            # doesn't "take"; prints: [0, 1, 2, 3]
x = s['akey']               # fetch the object
x.append(9)                 # perform mutation
s['akey'] = x               # key step: store the object back!
print(s['akey'])            # now it "takes", prints: [0, 1, 2, 3, 9]
```

You can finesse this issue by passing the named argument `writeback=True` when you call `shelve.open`, but this can seriously impair the performance of your program.

A shelving example

The following example handles the same task as the earlier `json` and `pickle` examples, but uses `shelve` to persist lists of (*`filename, linenumber`*) pairs:

```
import collections, fileinput, shelve
word_pos = collections.defaultdict(list)
for line in fileinput.input():
    pos = fileinput.filename(), fileinput.filelineno()
    for word in line.split():
        word_pos[word].append(pos)
with shelve.open('indexfiles','n') as sh_out:
    sh_out.update(word_pos)
```

3 `dbm` keys and values must be bytes; `shelve` will accept bytes or `str` and encode the strings transparently.

We must then use `shelve` to read back the data stored to the DBM-like file *index-files*, as shown in the following example:

```
import sys, shelve, linecache
with shelve.open('indexfiles') as sh_in:
    for word in sys.argv[1:]:
        if word not in sh_in:
            print(f'Word {word!r} not found in index file',
                  file=sys.stderr)
            continue
        places = sh_in[word]
        for fname, lineno in places:
            print(f'Word {word!r} occurs in line {lineno}'
                  f' of file {fname!r}:')
            print(linecache.getline(fname, lineno), end='')
```

These two examples are the simplest and most direct of the various equivalent pairs of examples shown throughout this section. This reflects the fact that `shelve` is higher level than the modules used in previous examples.

DBM Modules

DBM, a longtime Unix mainstay, is a family of libraries supporting data files containing pairs of bytestrings (*`key, data`*). DBM offers fast fetching and storing of the data given a key, a usage pattern known as *keyed access*. Keyed access, while nowhere near as powerful as the data access functionality of relational DBs, imposes less overhead, and it may suffice for some programs' needs. If DBM-like files are sufficient for your purposes, with this approach you can end up with a program that is smaller and faster than one using a relational DB.

DBM Databases Are Bytes-Oriented

DBM databases require both keys and values to be bytes values. You will see in the example included later that the text input is explicitly encoded in UTF-8 before storage. Similarly, the inverse decoding must be performed when reading back the values.

DBM support in Python's standard library is organized in a clean and elegant way: the `dbm` package exposes two general functions, and within the same package live other modules supplying specific implementations.

Berkeley DB Interfacing

The `bsddb` module has been removed from the Python standard library. If you need to interface to a BSD DB archive, we recommend the excellent third-party package bsddb3.

The dbm Package

The `dbm` package provides the top-level functions described in Table 12-6.

Table 12-6. Functions of the `dbm` package

`open` — `open(`*`filepath`*`, flag='r', mode=0o666)`

Opens or creates the DBM file named by *`filepath`* (any path to a file) and returns a mapping object corresponding to the DBM file. When the DBM file already exists, `open` uses the function `whichdb` to determine which DBM submodule can handle the file. When `open` creates a new DBM file, it chooses the first available `dbm` submodule in the following order of preference: `gnu`, `ndbm`, `dumb`.

`flag` is a one-character string that tells `open` how to open the file and whether to create it, according to the rules shown in Table 12-7. `mode` is an integer that `open` uses as the file's permission bits if `open` creates the file, as covered in "Creating a File Object with open" on page 323.

Table 12-7. Flag values for `dbm.open`

Flag	Read-only?	If file exists:	If file does not exist:
`'r'`	Yes	Opens the file	Raises error
`'w'`	No	Opens the file	Raises error
`'c'`	No	Opens the file	Creates the file
`'n'`	No	Truncates the file	Creates the file

`dbm.open` returns a mapping object *m* with a subset of the functionality of dictionaries (covered in "Dictionary Operations" on page 71). *m* only accepts `bytes` as keys and values, and the only nonspecial mapping methods *m* supplies are *m*`.get`, *m*`.keys`, and *m*`.setdefault`. You can bind, rebind, access, and unbind items in *m* with the same indexing syntax *m*`[`*`key`*`]` that you would use if *m* were a dictionary. If `flag` is `'r'`, *m* is read-only, so that you can only access *m*'s items, not bind, rebind, or unbind them. You can check if a string *s* is a key in *m* with the usual expression *s* **`in`** *m*; you cannot iterate directly on *m*, but you can, equivalently, iterate on *m*`.keys()`.

One extra method that *m* supplies is *m*`.close`, with the same semantics as the `close` method of a file object. Just like for file objects, you should ensure *m*`.close` is called when you're done using *m*. The **`try/finally`** statement (covered in "try/finally" on page 198) is one way to ensure finalization, but the **`with`** statement, covered in "The with Statement and Context Managers" on page 201, is even better (you can use **`with`**, since *m* is a context manager).

`whichdb` — `whichdb(`*`filepath`*`)`

Opens and reads the file specified by *`filepath`* to discover which `dbm` submodule created the file. `whichdb` returns **None** when the file does not exist or cannot be opened and read. It returns `''` when the file exists and can be opened and read, but it is not possible to determine which `dbm` submodule created the file (typically, this means that the file is not a DBM file). If it can find out which module can read the DBM-like file, `whichdb` returns a string that names a `dbm` submodule, such as `'dbm.ndbm'`, `'dbm.dumb'`, or `'dbm.gdbm'`.

In addition to these two top-level functions, the dbm package contains specific modules, such as ndbm, gnu, and dumb, that provide various implementations of DBM functionality, which you normally access only via the these top-level functions. Third-party packages can install further implementation modules in dbm.

The only implementation module of the dbm package that's guaranteed to exist on all platforms is dumb. dumb has minimal DBM functionality and mediocre performance; its only advantage is that you can use it anywhere, since dumb does not rely on any library. You don't normally **import** dbm.dumb: rather, **import** dbm, and let dbm.open supply the best DBM module available, defaulting to dumb if no better submodule is available in the current Python installation. The only case in which you import dumb directly is the rare one in which you need to create a DBM-like file that must be readable in any Python installation. The dumb module supplies an open function polymorphic to dbm's.

Examples of DBM-Like File Use

DBM's keyed access is suitable when your program needs to record persistently the equivalent of a Python dictionary, with strings as both keys and values. For example, suppose you need to analyze several text files, whose names are given as your program's arguments, and record where each word appears in those files. In this case, the keys are words and, therefore, intrinsically strings. The data you need to record for each word is a list of (*filename, linenumber*) pairs. However, you can encode the data as a string in several ways—for example, by exploiting the fact that the path separator string, os.pathsep (covered in "Path-string attributes of the os module" on page 344), does not normally appear in filenames. (More general approaches to the issue of encoding data as strings were covered in the opening section of this chapter, with the same example.) With this simplification, a program to record word positions in files might be as follows:

```
import collections, fileinput, os, dbm
word_pos = collections.defaultdict(list)
for line in fileinput.input():
    pos = f'{fileinput.filename()}{os.pathsep}{fileinput.filelineno()}'
    for word in line.split():
        word_pos[word].append(pos)
sep2 = os.pathsep * 2
with dbm.open('indexfile','n') as dbm_out:
    for word in word_pos:
        dbm_out[word.encode('utf-8')] = sep2.join(
                        word_pos[word]
                 ).encode('utf-8')
```

You can read back the data stored to the DBM-like file *indexfile* in several ways. The following example accepts words as command-line arguments and prints the lines where the requested words appear:

```
import sys, os, dbm, linecache

sep = os.pathsep
```

```
sep2 = sep * 2
with dbm.open('indexfile') as dbm_in:
    for word in sys.argv[1:]:
        e_word = word.encode('utf-8')
        if e_word not in dbm_in:
            print(f'Word {word!r} not found in index file',
                  file=sys.stderr)
            continue
        places = dbm_in[e_word].decode('utf-8').split(sep2)
        for place in places:
            fname, lineno = place.split(sep)
            print(f'Word {word!r} occurs in line {lineno}'
                  f' of file {fname!r}:')
            print(linecache.getline(fname, int(lineno)), end='')
```


The Python Database API (DBAPI)

As we mentioned earlier, the Python standard library does not come with an RDBMS interface (except for `sqlite3`, covered in "SQLite" on page 405, which is a rich implementation, not just an interface). Many third-party modules let your Python programs access specific DBs. Such modules mostly follow the Python Database API 2.0 standard, aka the DBAPI, as specified in PEP 249.

After importing any DBAPI-compliant module, you can call the module's `connect` function with DB-specific parameters. `connect` returns *x*, an instance of `Connection`, which represents a connection to the DB. *x* supplies `commit` and `rollback` methods to deal with transactions, a `close` method to call as soon as you're done with the DB, and a `cursor` method to return *c*, an instance of `Cursor`. *c* supplies the methods and attributes used for DB operations. A DBAPI-compliant module also supplies exception classes, descriptive attributes, factory functions, and type-description attributes.

Exception Classes

A DBAPI-compliant module supplies the exception classes `Warning`, `Error`, and several subclasses of `Error`. `Warning` indicates anomalies such as data truncation on insertion. `Error`'s subclasses indicate various kinds of errors that your program can encounter when dealing with the DB and the DBAPI-compliant module that interfaces to it. Generally, your code uses a statement of the form:

```
try:
    ...
except module.Error as err:
    ...
```

to trap all DB-related errors that you need to handle without terminating.

Thread Safety

When a DBAPI-compliant module has a `threadsafety` attribute greater than `0`, the module is asserting some level of thread safety for DB interfacing. Rather than relying on this, it's usually safer, and always more portable, to ensure that a single thread has exclusive access to any given external resource, such as a DB, as outlined in "Threaded Program Architecture" on page 471.

Parameter Style

A DBAPI-compliant module has an attribute called `paramstyle` to identify the style of markers used as placeholders for parameters. Insert such markers in SQL statement strings that you pass to methods of `Cursor` instances, such as the method `execute`, to use runtime-determined parameter values. Say, for example, that you need to fetch the rows of DB table *`ATABLE`* where field *`AFIELD`* equals the current value of Python variable *x*. Assuming the cursor instance is named *c*, you *could* theoretically (but very ill-advisedly!) perform this task with Python's string formatting:

```
c.execute(f'SELECT * FROM ATABLE WHERE AFIELD={x!r}')
```

> **Avoid SQL Query String Formatting: Use Parameter Substitution**
>
> String formatting is *not* the recommended approach. It generates a different string for each value of *x*, requiring statements to be parsed and prepared anew each time; it also opens up the possibility of security weaknesses, such as SQL injection vulnerabilities. With parameter substitution, you pass to `execute` a single statement string, with a placeholder instead of the parameter value. This lets `execute` parse and prepare the statement just once, for better performance; more importantly, parameter substitution improves solidity and security, hampering SQL injection attacks.

For example, when a module's `paramstyle` attribute (described next) is `'qmark'`, you could express the preceding query as:

```
c.execute('SELECT * FROM ATABLE WHERE AFIELD=?', (some_value,))
```

The read-only string attribute `paramstyle` tells your program how it should use parameter substitution with that module. The possible values of `paramstyle` are shown in Table 12-8.

Table 12-8. Possible values of the `paramstyle` attribute

`format`	The marker is `%s`, as in old-style string formatting (always with `s`: never use other type indicator letters, whatever the data's type). A query looks like: `c.execute('SELECT * FROM ATABLE WHERE AFIELD=%s', (some_value,))`

`named`	The marker is `:`*`name`*, and parameters are named. A query looks like:
	`c.execute('SELECT * FROM ATABLE WHERE AFIELD=:x',`
	`{'x':some_value})`

`numeric`	The marker is `:n`, giving the parameter's number, 1 and up. A query looks like:
	`c.execute('SELECT * FROM ATABLE WHERE AFIELD=:1',`
	`(some_value,))`

`pyformat`	The marker is `%(`*`name`*`)s`, and parameters are named. Always use `s`: never use other type indicator letters, whatever the data's type. A query looks like:
	`c.execute('SELECT * FROM ATABLE WHERE AFIELD=%(x)s',`
	`{'x':some_value})`

`qmark`	The marker is `?`. A query looks like: `c.execute('SELECT * FROM ATABLE WHERE AFIELD=?', (x,))`

When parameters are named (i.e., when `paramstyle` is `'pyformat'` or `'named'`), the second argument of the `execute` method is a mapping. Otherwise, the second argument is a sequence.

format and pyformat Only Accept Type Indicator s

The *only* valid type indicator letter for `format` or `pyformat` is `s`; neither accepts any other type indicator—for example, never use `%d` or `%(`*`name`*`)d`. Use `%s` or `%(`*`name`*`)s` for all parameter substitutions, regardless of the type of the data.

Factory Functions

Parameters passed to the DB via placeholders must typically be of the right type: this means Python numbers (integers or floating-point values), strings (bytes or Unicode), and **`None`** to represent SQL `NULL`. There is no type universally used to represent dates, times, and binary large objects (BLOBs). A DBAPI-compliant module supplies factory functions to build such objects. The types used for this purpose by most DBAPI-compliant modules are those supplied by the `datetime` module (covered in Chapter 13), and strings or buffer types for BLOBs. The factory functions specified by the DBAPI are listed in Table 12-9. (The `*FromTicks` methods take an integer timestamp *`s`* representing the number of seconds since the epoch of module `time`, covered in Chapter 13.)

Table 12-9. DBAPI factory functions

`Binary`	`Binary(`*`string`*`)` Returns an object representing the given *`string`* of bytes as a BLOB.
`Date`	`Date(`*`year`*`,`*`month`*`,`*`day`*`)` Returns an object representing the specified date.
`DateFrom Ticks`	`DateFromTicks(`*`s`*`)` Returns an object representing the date for integer timestamp *`s`*. For example, `DateFromTicks(time.time())` means "today."

`Time`	`Time(hour, minute, second)` Returns an object representing the specified time.
`TimeFromTicks`	`TimeFromTicks(s)` Returns an object representing the time for integer timestamp *s*. For example, `TimeFromTicks(time.time())` means "the current time of day."
`Timestamp`	`Timestamp(year, month, day, hour, minute, second)` Returns an object representing the specified date and time.
`TimestampFromTicks`	`TimestampFromTicks(s)` Returns an object representing the date and time for integer timestamp *s*. For example, `TimestampFromTicks(time.time())` is the current date and time.

Type Description Attributes

A `Cursor` instance's `description` attribute describes the types and other characteristics of each column of the `SELECT` query you last executed on that cursor. Each column's *type* (the second item of the tuple describing the column) equals one of the following attributes of the DBAPI-compliant module:

`BINARY`	Describes columns containing BLOBs
`DATETIME`	Describes columns containing dates, times, or both
`NUMBER`	Describes columns containing numbers of any kind
`ROWID`	Describes columns containing a row-identification number
`STRING`	Describes columns containing text of any kind

A cursor's description, and in particular each column's type, is mostly useful for introspection about the DB your program is working with. Such introspection can help you write general modules and work with tables using different schemas, including schemas that may not be known at the time you are writing your code.

The connect Function

A DBAPI-compliant module's `connect` function accepts arguments that depend on the kind of DB and the specific module involved. The DBAPI standard recommends that `connect` accept named arguments. In particular, `connect` should at least accept optional arguments with the following names:

`database`	Name of the specific database to connect to
`dsn`	Name of the data source to use for the connection
`host`	Hostname on which the database is running
`password`	Password to use for the connection
`user`	Username to use for the connection

Connection Objects

A DBAPI-compliant module's `connect` function returns an object *x* that is an instance of the class `Connection`. *x* supplies the methods listed in Table 12-10.

Table 12-10. Methods of an instance x of class Connection

`close`	`x.close()` Terminates the DB connection and releases all related resources. Call `close` as soon as you're done with the DB. Keeping DB connections open needlessly can be a serious resource drain on the system.
`commit`	`x.commit()` Commits the current transaction in the DB. If the DB does not support transactions, `x.commit()` is an innocuous no-op.
`cursor`	`x.cursor()` Returns a new instance of the class `Cursor` (covered in the following section).
`rollback`	`x.rollback()` Rolls back the current transaction in the DB. If the DB does not support transactions, `x.rollback()` raises an exception. The DBAPI recommends that, for DBs that do not support transactions, the class `Connection` supplies no `rollback` method, so that `x.rollback()` raises `AttributeError`: you can test whether transactions are supported with `hasattr(x, 'rollback')`.

Cursor Objects

A Connection instance provides a `cursor` method that returns an object *c* that is an instance of the class `Cursor`. A SQL cursor represents the set of results of a query and lets you work with the records in that set, in sequence, one at a time. A cursor as modeled by the DBAPI is a richer concept, since it's the only way your program executes SQL queries in the first place. On the other hand, a DBAPI cursor allows you only to advance in the sequence of results (some relational DBs, but not all, also provide higher-functionality cursors that are able to go backward as well as forward), and does not support the SQL clause `WHERE CURRENT OF CURSOR`. These limitations of DBAPI cursors enable DBAPI-compliant modules to provide DBAPI cursors even on RDBMSs that supply no real SQL cursors at all. An instance *c* of the class `Cursor` supplies many attributes and methods; the most frequently used ones are shown in Table 12-11.

Table 12-11. Commonly used attributes and methods of an instance `c` of class `Cursor`

`close`	`c.close()` Closes the cursor and releases all related resources.
`description`	A read-only attribute that is a sequence of seven-item tuples, one per column in the last query executed: `name`, `typecode`, `displaysize`, `internalsize`, `precision`, `scale`, `nullable` `c.description` is **None** if the last operation on *c* was not a `SELECT` query or returned no usable description of the columns involved. A cursor's description is mostly useful for introspection about the DB your program is working with. Such introspection can help you write general modules that are able to work with tables using different schemas, including schemas that may not be fully known at the time you are writing your code.
`execute`	`c.execute(`*`statement`*`, parameters=`**`None`**`)` Executes a SQL *`statement`* string on the DB with the given `parameters`. `parameters` is a sequence when the module's `paramstyle` is `'format'`, `'numeric'`, or `'qmark'`, and a mapping when `paramstyle` is `'named'` or `'pyformat'`. Some DBAPI modules require the sequences to be specifically tuples.

`executemany`	`c.executemany(`*`statement`*`, *`*`parameters`*`)`
	Executes a SQL *`statement`* on the DB, once for each item of the given *`parameters`*. *`parameters`* is a sequence of sequences when the module's `paramstyle` is `'format'`, `'numeric'`, or `'qmark'`, and a sequence of mappings when `paramstyle` is `'named'` or `'pyformat'`. For example, when `paramstyle` is `'qmark'`, the statement:
	`c.executemany('UPDATE atable SET x=? '`
	`              'WHERE y=?',(12,23),(23,34))`
	is equivalent to—but faster than—the two statements:
	`c.execute('UPDATE atable SET x=12 WHERE y=23')`
	`c.execute('UPDATE atable SET x=23 WHERE y=34')`

`fetchall`	`c.fetchall()` Returns all remaining rows from the last query as a sequence of tuples. Raises an exception if the last operation was not a `SELECT`.
`fetchmany`	`c.fetchmany(`*`n`*`)` Returns up to *n* remaining rows from the last query as a sequence of tuples. Raises an exception if the last operation was not a `SELECT`.
`fetchone`	`c.fetchone()` Returns the next row from the last query as a tuple. Raises an exception if the last operation was not a `SELECT`.
`rowcount`	A read-only attribute that specifies the number of rows fetched or affected by the last operation, or `-1` if the module is unable to determine this value.

DBAPI-Compliant Modules

Whatever relational DB you want to use, there's at least one (often more than one) Python DBAPI-compliant module downloadable from the internet. There are so many DBs and modules, and the set of possibilities changes so constantly, that we couldn't possibly list them all, nor (importantly) could we maintain the list over time. Rather, we recommend you start from the community-maintained wiki page, which has at least a fighting chance to be complete and up-to-date at any time.

What follows is therefore only a very short, time-specific list of a very few DBAPI-compliant modules that, at the time of writing, are very popular and interface to very popular open source DBs:

ODBC modules
: Open Database Connectivity (ODBC) is a standard way to connect to many different DBs, including a few not supported by other DBAPI-compliant modules. For an ODBC-compliant DBAPI-compliant module with a liberal open source license, use `pyodbc`; for a commercially supported one, use mxODBC.

MySQL modules
: MySQL is a popular open source RDBMS, purchased by Oracle in 2010. Oracle's "official" DBAPI-compliant interface to it is `mysql-connector-python`. The MariaDB project also provides a DBAPI-compliant interface, `mariadb`, connecting to both MySQL and MariaDB (a GPL-licensed fork).

PostgreSQL modules
: PostgreSQL is another popular open source RDBMS. A widely used DBAPI-compliant interface to it is `psycopg3`, a rationalized rewrite and extension of the hallowed `psycopg2` package.

Persistence and Databases

SQLite

SQLite is a C-coded library that implements a relational DB within a single file, or even in memory for sufficiently small and transient cases. Python's standard library supplies the package `sqlite3`, which is a DBAPI-compliant interface to SQLite.

SQLite has rich advanced functionality, with many options you can choose; `sqlite3` offers access to much of that functionality, plus further possibilities to make interoperation between your Python code and the underlying DB smoother and more natural. We don't have the space in this book to cover every nook and cranny of these two powerful software systems; instead, we focus on the subset of functions that are most commonly used and most useful. For a greater level of detail, including examples and tips on best practices, see the documentation for SQLite and `sqlite3`, and Jay Kreibich's *Using SQLite* (O'Reilly).

Among others, the `sqlite3` package supplies the functions in Table 12-12.

Table 12-12. Some useful functions of the `sqlite3` module

`connect`	`connect(`*`filepath`*`, timeout=5.0, detect_types=0, isolation_level='', check_same_thread=`**`True`**`, factory=Connection, cached_statements=100, uri=`**`False`**`)` Connects to the SQLite DB in the file named by *`filepath`* (creating it if necessary) and returns an instance of the `Connection` class (or subclass thereof passed as `factory`). To create an in-memory DB, pass `':memory:'` as the first argument, *`filepath`*. If **`True`**, the `uri` argument activates SQLite's URI functionality, allowing a few extra options to be passed along with the filepath via the *`filepath`* argument. `timeout` is the number of seconds to wait before raising an exception if another connection is keeping the DB locked in a transaction. `sqlite3` directly supports only the following SQLite native types, converting them to the indicated Python types: • `BLOB`: Converted to `bytes` • `INTEGER`: Converted to `int` • `NULL`: Converted to **`None`** • `REAL`: Converted to `float` • `TEXT`: Depends on the `text_factory` attribute of the `Connection` instance, covered in Table 12-13; by default, `str` Any other type name is treated as `TEXT` unless properly detected and passed through a converter registered with the function `register_converter`, covered later in this table. To allow type name detection, pass as `detect_types` either of the constants `PARSE_COLNAMES` or `PARSE_DECLTYPES`, supplied by the `sqlite3` package (or both, joining them with the `|` bitwise OR operator). When you pass `detect_types=sqlite3.PARSE_COLNAMES`, the type name is taken from the name of the column in the SQL `SELECT` statement that retrieves the column; for example, a column retrieved as *foo* `AS [`*foo* `CHAR(10)]` has a type name of `CHAR`. When you pass `detect_types=sqlite3.PARSE_DECLTYPES`, the type name is taken from the declaration of the column in the original `CREATE TABLE` or `ALTER TABLE` SQL statement that added the column; for example, a column declared as *foo* `CHAR(10)` has a type name of `CHAR`. When you pass `detect_types=sqlite3.PARSE_COLNAMES | sqlite3.PARSE_DECLTYPES`, both mechanisms are used, with precedence given to the column name when it has at least two words (the second word gives the type name in this case), falling back to the type that was given for that column at declaration (the first word of the declaration type gives the type name in this case). `isolation_level` lets you exercise some control over how SQLite processes transactions; it can be `''` (the default), **`None`** (to use *autocommit* mode), or one of the three strings `'DEFERRED'`, `'EXCLUSIVE'`, or `'IMMEDIATE'`. The SQLite online docs cover the details of types of transactions and their relation to the various levels of file locking that SQLite intrinsically performs.

`connect` *(cont.)*	By default, a connection object can be used only in the Python thread that created it, to avoid accidents that could easily corrupt the DB due to minor bugs in your program (minor bugs are, alas, common in multithreaded programming). If you're entirely confident about your threads' use of locks and other synchronization mechanisms, and you need to reuse a connection object among multiple threads, you can pass `check_same_thread=False`. `sqlite3` will then perform no checks, trusting your assertion that you know what you're doing and that your multithreading architecture is 100% bug-free—good luck! `cached_statements` is the number of SQL statements that `sqlite3` caches in a parsed and prepared state, to avoid the overhead of parsing them repeatedly. You can pass in a value lower than the default `100` to save a little memory, or a larger one if your application uses a dazzling variety of SQL statements.
`register_adapter`	`register_adapter(`*`type`*`, `*`callable`*`)` Registers *`callable`* as the *adapter* from any object of Python type *`type`* to a corresponding value of one of the few Python types that `sqlite3` handles directly: `int`, `float`, `str`, and `bytes`. *`callable`* must accept a single argument, the value to adapt, and return a value of a type that `sqlite3` handles directly.
`register_converter`	`register_converter(`*`typename`*`, `*`callable`*`)` Registers *`callable`* as the *converter* from any value identified in SQL as being of type *`typename`* (see the description of the connect function's `detect_types` parameter for an explanation of how the type name is identified) to a corresponding Python object. *`callable`* must accept a single argument, the string form of the value obtained from SQL, and return the corresponding Python object. The *`typename`* matching is case-sensitive.

In addition, `sqlite3` supplies the classes `Connection`, `Cursor`, and `Row`. Each can be subclassed for further customization; however, this is an advanced topic that we do not cover further in this book. The `Cursor` class is a standard DBAPI cursor class, except for an extra convenience method, `executescript`, accepting a single argument, a string of multiple statements separated by `;` (no parameters). The other two classes are covered in the following sections.

The sqlite3.Connection class

In addition to the methods common to all `Connection` classes of DBAPI-compliant modules, covered in "Connection Objects" on page 403, `sqlite3.Connection` supplies the methods and attributes in Table 12-13.

Table 12-13. Additional methods and attributes of the `sqlite3.Connection` class

`create_aggregate`	`create_aggregate(`*`name`*`, `*`num_params`*`, `*`aggregate_class`*`)` *`aggregate_class`* must be a class supplying two instance methods: `step`, accepting exactly *`num_param`* arguments, and *`finalize`*, accepting no arguments and returning the final result of the aggregate, a value of a type natively supported by `sqlite3`. The aggregate function can be used in SQL statements by the given *`name`*.

create_ collation	create_collation(*name*, *callable*) *callable* must accept two bytestring arguments (encoded in 'utf-8') and return -1 if the first must be considered "less than" the second, 1 if it must be considered "greater than," and 0 if it must be considered "equal," for the purposes of this comparison. Such a collation can be named by the given *name* in a SQL ORDER BY clause in a SELECT statement.
create_ function	create_function(*name*, *num_params*, *func*) *func* must accept exactly *num_params* arguments and return a value of a type natively supported by sqlite3; such a user-defined function can be used in SQL statements by the given *name*.
interrupt	interrupt() Call from any other thread to abort all queries executing on this connection (raising an exception in the thread using the connection).
isolation_ level	A read-only attribute that's the value given as the isolation_level parameter to the connect function.
iterdump	iterdump() Returns an iterator that yields strings: the SQL statements that build the current DB from scratch, including both the schema and contents. Useful, for example, to persist an in-memory DB to disk for future reuse.
row_factory	A callable that accepts the cursor and the original row as a tuple, and returns an object to use as the real result row. A common idiom is *x*.row_factory=sqlite3.Row, to use the highly optimized Row class covered in the following section, supplying both index-based and case-insensitive name-based access to columns with negligible overhead.
text_factory	A callable that accepts a single bytestring parameter and returns the object to use for that TEXT column value—by default, str, but you can set it to any similar callable.
total_changes	The total number of rows that have been modified, inserted, or deleted since the connection was created.

A Connection object can also be used as a context manager, to automatically commit database updates or roll back if an exception occurs; however, you will need to call Connection.close() explicitly to close the connection in this case.

The sqlite3.Row class

sqlite3 also supplies the class Row. A Row object is mostly like a tuple but also supplies the method keys, returning a list of column names, and supports indexing by a column name as an alternative to indexing by column number.

A sqlite3 example

The following example handles the same task as the examples shown earlier in the chapter, but uses `sqlite3` for persistence, without creating the index in memory:

```
import fileinput, sqlite3
connect = sqlite3.connect('database.db')
cursor = connect.cursor()
with connect:
    cursor.execute('CREATE TABLE IF NOT EXISTS Words '
                   '(Word TEXT, File TEXT, Line INT)')
    for line in fileinput.input():
        f, l = fileinput.filename(), fileinput.filelineno()
        cursor.executemany('INSERT INTO Words VALUES (:w, :f, :l)',
            [{'w':w, 'f':f, 'l':l} for w in line.split()])
connect.close()
```

We can then use `sqlite3` to read back the data stored in the DB file *database.db*, as shown in the following example:

```
import sys, sqlite3, linecache
connect = sqlite3.connect('database.db')
cursor = connect.cursor()
for word in sys.argv[1:]:
    cursor.execute('SELECT File, Line FROM Words '
                   'WHERE Word=?', [word])
    places = cursor.fetchall()
    if not places:
         print(f'Word {word!r} not found in index file',
               file=sys.stderr)
         continue
    for fname, lineno in places:
        print(f'Word {word!r} occurs in line {lineno}'
              f' of file {fname!r}:')
        print(linecache.getline(fname, lineno), end='')
connect.close()
```

13
Time Operations

A Python program can handle time in several ways. Time *intervals* are floating-point numbers in units of seconds (a fraction of a second is the fractional part of the interval): all standard library functions accepting an argument that expresses a time interval in seconds accept a float as the value of that argument. *Instants* in time are expressed in seconds since a reference instant, known as the *epoch*. (Although epochs vary per language and per platform, on all platforms, Python's epoch is midnight, UTC, January 1, 1970.) Time instants often also need to be expressed as a mixture of units of measurement (e.g., years, months, days, hours, minutes, and seconds), particularly for I/O purposes. I/O, of course, also requires the ability to format times and dates into human-readable strings, and parse them back from string formats.

The time Module

The `time` module is somewhat dependent on the underlying system's C library, which sets the range of dates that the `time` module can handle. On older Unix systems, the years 1970 and 2038 were typical cutoff points[1] (a limitation avoided by using `datetime`, discussed in the following section). Time instants are normally specified in UTC (Coordinated Universal Time, once known as GMT, or Greenwich

1 On older Unix systems, 1970-01-01 is the start of the epoch, and 2038-01-19 is when 32-bit time wraps back to the epoch. Most modern systems now use 64-bit time, and many `time` methods can accept a year from 0001 to 9999, but some methods, or old systems (especially embedded ones), may still be limited.

Mean Time). The `time` module also supports local time zones and daylight savings time (DST), but only to the extent the underlying C system library does.[2]

As an alternative to seconds since the epoch, a time instant can be represented by a tuple of nine integers, called a *timetuple* (covered in Table 13-1.) All the items are integers: timetuples don't keep track of fractions of a second. A timetuple is an instance of `struct_time`. You can use it as a tuple; you can also, more usefully, access the items as the read-only attributes *x*.tm_year, *x*.tm_mon, and so on, with the attribute names listed in Table 13-1. Wherever a function requires a timetuple argument, you can pass an instance of `struct_time` or any other sequence whose items are nine integers in the right ranges (all ranges in the table include both lower and upper bounds, both inclusive).

Table 13-1. Tuple form of time representation

Item	Meaning	Field name	Range	Notes
0	Year	tm_year	1970–2038	0001–9999 on some platforms
1	Month	tm_mon	1–12	1 is January; 12 is December
2	Day	tm_mday	1–31	
3	Hour	tm_hour	0–23	0 is midnight; 12 is noon
4	Minute	tm_min	0–59	
5	Second	tm_sec	0–61	60 and 61 for leap seconds
6	Weekday	tm_wday	0–6	0 is Monday; 6 is Sunday
7	Year day	tm_yday	1–366	Day number within the year
8	DST flag	tm_isdst	−1–1	−1 means the library determines DST

To translate a time instant from a "seconds since the epoch" floating-point value into a timetuple, pass the floating-point value to a function (e.g., `localtime`) that returns a timetuple with all nine items valid. When you convert in the other direction, `mktime` ignores redundant items 6 (tm_wday) and 7 (tm_yday) of the tuple. In this case, you normally set item 8 (tm_isdst) to −1 so that `mktime` itself determines whether to apply DST.

`time` supplies the functions and attributes listed in Table 13-2.

2 `time` and `datetime` don't account for leap seconds, since their schedule is not known for the future.

Table 13-2. Functions and attributes of the `time` module

asctime	asctime([*tupletime*]) Accepts a timetuple and returns a readable 24-character string, e.g., 'Sun Jan 8 14:41:06 2017'. Calling asctime() without arguments is like calling asctime(time.localtime()) (formats current time in local time).
ctime	ctime([*secs*]) Like asctime(localtime(*secs*)), accepts an instant expressed in seconds since the epoch and returns a readable 24-character string form of that instant, in local time. Calling ctime() without arguments is like calling asctime() (formats current time in local time).
gmtime	gmtime([*secs*]) Accepts an instant expressed in seconds since the epoch and returns a timetuple *t* with the UTC time (*t*.tm_isdst is always 0). Calling gmtime() without arguments is like calling gmtime(time()) (returns the timetuple for the current time instant).
localtime	localtime([*secs*]) Accepts an instant expressed in seconds since the epoch and returns a timetuple *t* with the local time (*t*.tm_isdst is 0 or 1, depending on whether DST applies to instant *secs* by local rules). Calling localtime() without arguments is like calling localtime(time()) (returns the timetuple for the current time instant).
mktime	mktime(*tupletime*) Accepts an instant expressed as a timetuple in local time and returns a floating-point value with the instant expressed in seconds since the epoch (only accepts the limited epoch dates between 1970–2038, not the extended range, even on 64-bit machines).[a] The DST flag, the last item in *tupletime*, is meaningful: set it to 0 to get standard time, to 1 to get DST, or to –1 to let mktime compute whether DST is in effect at the given instant.
monotonic	monotonic() Like time(), returns the current time instant, a float with seconds since the epoch; however, the time value is guaranteed to never go backward between calls, even when the system clock is adjusted (e.g., due to leap seconds or at the moment of switching to or from DST).
perf_counter	perf_counter() For determining elapsed time between successive calls (like a stopwatch), perf_counter returns a time value in fractional seconds using the highest-resolution clock available to get accuracy for short durations. It is system-wide and *includes* time elapsed during sleep. Use only the difference between successive calls, as there is no defined reference point.
process_time	process_time() Like perf_counter; however, the returned time value is process-wide and *doesn't* include time elapsed during sleep. Use only the difference between successive calls, as there is no defined reference point.

Time Operations

`sleep`	`sleep(secs)` Suspends the calling thread for *`secs`* seconds. The calling thread may start executing again before *`secs`* seconds (when it's the main thread and some signal wakes it up) or after a longer suspension (depending on system scheduling of processes and threads). You can call sleep with *`secs`* set to `0` to offer other threads a chance to run, incurring no significant delay if the current thread is the only one ready to run.
`strftime`	`strftime(fmt[, tupletime])` Accepts an instant expressed as a timetuple in local time and returns a string representing the instant as specified by string *`fmt`*. If you omit *`tupletime`*, `strftime` uses `localtime(time())` (formats the current time instant). The syntax of *`fmt`* is similar to that covered in "Legacy String Formatting with %" on page 297, though the conversion characters are different, as shown in Table 13-3. Refer to the time instant specified by *`tupletime`*; the format can't specify width and precision. For example, you can obtain dates just as formatted by `asctime` (e.g., `'Tue Dec 10 18:07:14 2002'`) with the format string `'%a %b %d %H:%M:%S %Y'`. You can obtain dates compliant with RFC 822 (e.g., `'Tue, 10 Dec 2002 18:07:14 EST'`) with the format string `'%a, %d %b %Y %H:%M:%S %Z'`. These strings can also be used for `datetime` formatting using the mechanisms discussed in "Formatting of User-Coded Classes" on page 296, allowing you to equivalently write, for a `datetime.datetime` object d, either `f'{d:%Y/%m/%d}'` or `'{:%Y/%m/%d}'.format(d)`, both of which give a result such as '2022/04/17'. For ISO 8601–format `datetime`s, see the `isoformat()` and `fromisoformat()` methods covered in "The date Class" on page 416.

`strptime`	`strptime(str, fmt)`
	Parses *`str`* according to format string *`fmt`* (a string such as `'%a %b %d %H:%M:%S %Y'`, as covered in the discussion of `strftime`) and returns the instant as a timetuple. If no time values are provided, defaults to midnight. If no date values are provided, defaults to January 1, 1900. For example:
	`>>> print(time.strptime("Sep 20, 2022", '%b %d, %Y'))`
	`time.struct_time(tm_year=2022, tm_mon=9, tm_mday=20, tm_hour=0, tm_min=0, tm_sec=0, tm_wday=1, tm_yday=263, tm_isdst=-1)`

`time`	`time()` Returns the current time instant, a `float` with seconds since the epoch. On some (mostly older) platforms, the precision of this time is as low as one second. May return a lower value in a subsequent call if the system clock is adjusted backward between calls (e.g., due to leap seconds).
`timezone`	The offset in seconds of the local time zone (without DST) from UTC (`<0` in the Americas; `>=0` in most of Europe, Asia, and Africa).
`tzname`	A pair of locale-dependent strings, which are the names of the local time zone without and with DST, respectively.

[a] `mktime`'s result's fractional part is always `0`, since its timetuple argument does not account for fractions of a second.

Table 13-3. Conversion characters for `strftime`

Type char	Meaning	Special notes
a	Weekday name, abbreviated	Depends on locale
A	Weekday name, full	Depends on locale
b	Month name, abbreviated	Depends on locale
B	Month name, full	Depends on locale
c	Complete date and time representation	Depends on locale
d	Day of the month	Between 1 and 31
f	Microsecond as decimal, zero-padded to six digits	One to six digits
G	ISO 8601:2000 standard week-based year number	
H	Hour (24-hour clock)	Between 0 and 23
I	Hour (12-hour clock)	Between 1 and 12
j	Day of the year	Between 1 and 366
m	Month number	Between 1 and 12
M	Minute number	Between 0 and 59
p	A.M. or P.M. equivalent	Depends on locale
S	Second number	Between 0 and 61
u	Day of week	Monday is 1, up to 7
U	Week number (Sunday first weekday)	Between 0 and 53
V	ISO 8601:2000 standard week-based week number	
w	Weekday number	0 is Sunday, up to 6
W	Week number (Monday first weekday)	Between 0 and 53
x	Complete date representation	Depends on locale
X	Complete time representation	Depends on locale
y	Year number within century	Between 0 and 99
Y	Year number	1970 to 2038, or wider
z	UTC offset as a string: ±HHMM[SS[.ffffff]]	
Z	Name of time zone	Empty if no time zone exists
%	A literal % character	Encoded as %%

The datetime Module

`datetime` provides classes for modeling date and time objects, which can be either *aware* of time zones or *naive* (the default). The class `tzinfo`, whose instances model a time zone, is abstract: the `datetime` module supplies only one simple implementation, `datetime.timezone` (for all the gory details, see the online docs). The `zoneinfo` module, covered in the following section, offers a richer concrete implementation of `tzinfo`, which lets you easily create time zone-aware `datetime` objects. All types in `datetime` have immutable instances: attributes are read-only, instances can be keys in a `dict` or items in a `set`, and all functions and methods return new objects, never altering objects passed as arguments.

The date Class

Instances of the `date` class represent a date (no time of day in particular within that date) between `date.min <= d <= date.max`, are always naive, and assume the Gregorian calendar was always in effect. `date` instances have three read-only integer attributes: *`year`*, *`month`*, and *`day`*. The constructor for this class has the signature:

date	**class** date(*year, month, day*) Returns a date object for the given *`year`*, *`month`*, and *`day`* arguments, in the valid ranges `1 <=` *`year`* `<= 9999`, `1 <=` *`month`* `<= 12`, and `1 <=` *`day`* `<=` *n*, where *n* is the number of days for the given month and year. Raises `ValueError` if invalid values are given.

The `date` class also supplies three class methods usable as alternative constructors, listed in Table 13-4.

Table 13-4. Alternative `date` constructors

fromordinal	`date.fromordinal(`*`ordinal`*`)` Returns a `date` object corresponding to the proleptic Gregorian ordinal *`ordinal`*, where a value of `1` corresponds to the first day of year 1 CE.
fromtimestamp	`date.fromtimestamp(`*`timestamp`*`)` Returns a `date` object corresponding to the instant *`timestamp`* expressed in seconds since the epoch.
today	`date.today()` Returns a `date` representing today's date.

Instances of the `date` class support some arithmetic. The difference between `date` instances is a `timedelta` instance; you can add or subtract a `timedelta` to or from a `date` instance to make another `date` instance. You can also compare any two instances of the `date` class (the later one is greater).

An instance *d* of the class `date` supplies the methods listed in Table 13-5.

Table 13-5. Methods of an instance d of class `date`

`ctime`	`d.ctime()` Returns a string representing the date *d* in the same 24-character format as `time.ctime` (with the time of day set to 00:00:00, midnight).
`isocalendar`	`d.isocalendar()` Returns a tuple with three integers (ISO year, ISO week number, and ISO weekday). See the ISO 8601 standard for more details about the ISO (International Standards Organization) calendar.
`isoformat`	`d.isoformat()` Returns a string representing date *d* in the format `'YYYY-MM-DD'`; same as `str(d)`.
`isoweekday`	`d.isoweekday()` Returns the day of the week of date *d* as an integer, `1` for Monday through `7` for Sunday; like `d.weekday() + 1`.

`replace`	`d.replace(year=None, month=None, day=None)`
	Returns a new `date` object, like *d* except for those attributes explicitly specified as arguments, which get replaced. For example:
	`date(x,y,z).replace(month=m) == date(x,m,z)`

`strftime`	`d.strftime(fmt)`
	Returns a string representing date *d* as specified by string *fmt*, like:
	`time.strftime(fmt, d.timetuple())`

`timetuple`	`d.timetuple()` Returns a timetuple corresponding to date *d* at time `00:00:00` (midnight).

`toordinal`	`d.toordinal()`
	Returns the proleptic Gregorian ordinal for date *d*. For example:
	`date(1,1,1).toordinal() == 1`

`weekday`	`d.weekday()` Returns the day of the week of date *d* as an integer, `0` for Monday through `6` for Sunday; like `d.isoweekday() - 1`.

The time Class

Instances of the `time` class represent a time of day (of no particular date), may be naive or aware regarding time zones, and always ignore leap seconds. They have five attributes: four read-only integers (`hour`, `minute`, `second`, and `microsecond`) and an optional read-only `tzinfo` (**`None`** for naive instances). The constructor for the `time` class has the signature:

`time`	**`class`** `time(hour=0, minute=0, second=0, microsecond=0, tzinfo=None)` Instances of the class `time` do not support arithmetic. You can compare two instances of `time` (the one that's later in the day is greater), but only if they are either both aware or both naive.

Time Operations

An instance *t* of the class `time` supplies the methods listed in Table 13-6.

Table 13-6. Methods of an instance `t` of class `time`

`isoformat`	`t.isoformat()` Returns a string representing time *t* in the format `'HH:MM:SS'`; same as `str(t)`. If `t.microsecond != 0`, the resulting string is longer: `'HH:MM:SS.mmmmmm'`. If *t* is aware, six more characters, `'+HH:MM'`, are added at the end to represent the time zone's offset from UTC. In other words, this formatting operation follows the ISO 8601 standard.

`replace`	`t.replace(hour=None, minute=None, second=None, microsecond=None[, tzinfo])`
	Returns a new `time` object, like *t* except for those attributes explicitly specified as arguments, which get replaced. For example:
	`time(x,y,z).replace(minute=m) == time(x,m,z)`

`strftime`	`t.strftime(fmt)` Returns a string representing time *t* as specified by the string *fmt*.

An instance *t* of the class `time` also supplies methods `dst`, `tzname`, and `utcoffset`, which accept no arguments and delegate to `t.tzinfo`, returning **`None`** when `t.tzinfo` is **`None`**.

The datetime Class

Instances of the `datetime` class represent an instant (a date, with a specific time of day within that date), may be naive or aware of time zones, and always ignore leap seconds. `datetime` extends `date` and adds `time`'s attributes; its instances have read-only integer attributes `year`, `month`, `day`, `hour`, `minute`, `second`, and `microsecond`, and an optional `tzinfo` attribute (**`None`** for naive instances). In addition, `datetime` instances have a readonly `fold` attribute to distinguish between ambiguous timestamps during a rollback of the clock (such as the "fall back" at the end of daylight savings time, which creates duplicate naive times between 1 A.M. and 2 A.M.). `fold` has the value `0` or `1` `0` corresponds to the time *before* the rollback; `1` to the time *after* the rollback.

Instances of `datetime` support some arithmetic: the difference between `datetime` instances (both aware, or both naive) is a `timedelta` instance, and you can add or subtract a `timedelta` instance to or from a `datetime` instance to construct another `datetime` instance. You can compare two instances of the `datetime` class (the later one is greater) as long as they're both aware or both naive. The constructor for this class has the signature:

`datetime`	**`class`** `datetime(year, month, day, hour=0, minute=0, second=0, microsecond=0, tzinfo=None, *, fold=0)` Returns a `datetime` object following similar constraints as the `date` class constructor. `fold` is an `int` with the value `0` or `1`, as described previously.

datetime also supplies some class methods usable as alternative constructors, covered in Table 13-7.

Table 13-7. Alternative datetime constructors

combine	datetime.combine(*date*, *time*)
	Returns a datetime object with the date attributes taken from *date* and the time attributes (including tzinfo) taken from *time*. datetime.combine(*d*, *t*) is like:
	`datetime(d.year, d.month, d.day,`
	`         t.hour, t.minute, t.second,`
	`         t.microsecond, t.tzinfo)`

fromordinal	datetime.fromordinal(*ordinal*) Returns a datetime object for the date given proleptic Gregorian ordinal *ordinal*, where a value of 1 means the first day of year 1 CE, at midnight.
fromtime stamp	datetime.fromtimestamp(*timestamp*, tz=**None**) Returns a datetime object corresponding to the instant *timestamp* expressed in seconds since the epoch, in local time. When tz is not **None**, returns an aware datetime object with the given tzinfo instance tz.
now	datetime.now(tz=**None**) Returns a naive datetime object for the current local date and time. When tz is not **None**, returns an aware datetime object with the given tzinfo instance tz.
strptime	datetime.strptime(*str*, *fmt*) Returns a datetime representing *str* as specified by string *fmt*. When %z is present in *fmt*, the resulting datetime object is time zone–aware.
today	datetime.today() Returns a naive datetime object representing the current local date and time; same as the now class method but does not accept optional argument *tz*.
utcfrom timestamp	datetime.utcfromtimestamp(*timestamp*) Returns a naive datetime object corresponding to the instant *timestamp* expressed in seconds since the epoch, in UTC.
utcnow	datetime.utcnow() Returns a naive datetime object representing the current date and time, in UTC.

An instance *d* of datetime also supplies the methods listed in Table 13-8.

Table 13-8. Methods of an instance d of datetime

astimezone	*d*.astimezone(*tz*) Returns a new aware datetime object, like *d*, except that the date and time are converted along with the time zone to the one in tzinfo object *tz*.[a] *d* must be aware, to avoid potential bugs. Passing a naive *d* may lead to unexpected results.
ctime	*d*.ctime() Returns a string representing date and time *d* in the same 24-character format as time.ctime.

Time Operations

`date`	*d*`.date()` Returns a date object representing the same date as *d*.
`isocalendar`	*d*`.isocalendar()` Returns a tuple with three integers (ISO year, ISO week number, and ISO weekday) for *d*'s date.
`isoformat`	*d*`.isoformat(sep='T')` Returns a string representing *d* in the format `'YYYY-MM-DDxHH:MM:SS'`, where *x* is the value of argument `sep` (must be a string of length 1). If *d*`.microsecond != 0`, seven characters, `'.mmmmmm'`, are added after the `'SS'` part of the string. If *t* is aware, six more characters, `'+HH:MM'`, are added at the end to represent the time zone's offset from UTC. In other words, this formatting operation follows the ISO 8601 standard. `str(`*d*`)` is the same as *d*`.isoformat(sep=' ')`.
`isoweekday`	*d*`.isoweekday()` Returns the day of the week of *d*'s date as an integer, `1` for Monday through `7` for Sunday.

`replace`	*d*`.replace(year=`**`None`**`, month=`**`None`**`, day=`**`None`**`, hour=`**`None`**`, minute=`**`None`**`, second=`**`None`**`, microsecond=`**`None`**`, tzinfo=`**`None`**`,*, fold=0)`
	Returns a new `datetime` object, like *d* except for those attributes specified as arguments, which get replaced (but does *no* time zone conversion—use `astimezone` if you want the time converted). You can also use `replace` to create an aware `datetime` object from a naive one. For example:
	`# create datetime replacing just month with no`
	`# other changes (== datetime(x,m,z))`
	`datetime(x,y,z).replace(month=m)`
	`# create aware datetime from naive datetime.now()`
	`d = datetime.now().replace(tzinfo=ZoneInfo(`
	`                            "US/Pacific"))`

`strftime`	*d*`.strftime(`*`fmt`*`)` Returns a string representing *d* as specified by the format string *`fmt`*.
`time`	*d*`.time()` Returns a naive `time` object representing the same time of day as *d*.
`timestamp`	*d*`.timestamp()` Returns a float with the seconds since the epoch. Naive instances are assumed to be in the local time zone.
`timetuple`	*d*`.timetuple()` Returns a timetuple corresponding to instant *d*.
`timetz`	*d*`.timetz()` Returns a `time` object representing the same time of day as *d*, with the same `tzinfo`.
`toordinal`	*d*`.toordinal()` Returns the proleptic Gregorian ordinal for *d*'s date. For example: `datetime(1, 1, 1).toordinal() == 1`
`utctime` `tuple`	*d*`.utctimetuple()` Returns a timetuple corresponding to instant *d*, normalized to UTC if *d* is aware.

`weekday`	`d.weekday()` Returns the day of the week of *d*'s date as an integer, `0` for Monday through `6` for Sunday.

[a] Note that `d.astimezone(tz)` is quite different from `d.replace(tzinfo=tz)`: `replace` does no time zone conversion, but rather just copies all of *d*'s attributes except for `d.tzinfo`.

An instance *d* of the class `datetime` also supplies the methods `dst`, `tzname`, and `utcoffset`, which accept no arguments and delegate to `d.tzinfo`, returning **`None`** when `d.tzinfo` is **`None`** (i.e., when *d* is naive).

The timedelta Class

Instances of the `timedelta` class represent time intervals with three read-only integer attributes: `days`, `seconds`, and `microseconds`. The constructor for this class has the signature:

`timedelta` — `timedelta(days=0, seconds=0, microseconds=0, milliseconds=0, minutes=0, hours=0, weeks=0)`

Converts all units with the obvious factors (a week is 7 days, an hour is 3,600 seconds, and so on) and normalizes everything to the three integer attributes, ensuring that `0 <= seconds < 24 * 60 * 60` and `0 <= microseconds < 1000000`. For example:

```
>>> print(repr(timedelta(minutes=0.5)))
datetime.timedelta(days=0, seconds=30)
>>> print(repr(timedelta(minutes=-0.5)))
datetime.timedelta(days=-1, seconds=86370)
```

Instances of `timedelta` support arithmetic: `+` and `-` between themselves and with instances of the classes `date` and `datetime`; `*` with integers; `/` with integers and `timedelta` instances (floor division, true division, `divmod`, `%`). They also support comparisons between themselves.

While `timedelta` instances can be created using this constructor, they are more often created by subtracting two `date`, `time`, or `datetime` instances, such that the resulting `timedelta` represents an elapsed time period. An instance *td* of `timedelta` supplies a method `td.total_seconds()` that returns a float representing the total seconds of a `timedelta` instance.

The tzinfo Abstract Class

The `tzinfo` class defines the abstract class methods listed in Table 13-9, to support creation and usage of aware `datetime` and `time` objects.

Table 13-9. Methods of the `tzinfo` class

`dst`	`dst(dt)` Returns the daylight savings offset of a given `datetime`, as a `timedelta` object
`tzname`	`tzname(dt)` Returns the abbreviation for the time zone of a given `datetime`

`utcoffset`	`utcoffset(dt)` Returns the offset from UTC of a given `datetime`, as a `timedelta` object	

`tzinfo` also defines a `fromutc` abstract instance method, primarily for internal use by the `datetime.astimezone` method.

The timezone Class

The `timezone` class is a concrete implementation of the `tzinfo` class. You construct a `timezone` instance using a `timedelta` representing the time offset from UTC. `timezone` supplies one class property, `utc`, a `timezone` representing the UTC time zone (equivalent to `timezone(timedelta(0))`).

The zoneinfo Module

3.9+ The `zoneinfo` module is a concrete implementation of timezones for use with datetime's `tzinfo`.[3] `zoneinfo` uses the system's time zone data by default, with `tzdata` as a fallback. (On Windows, you may need to **`pip install tzdata`**; once installed, you don't import `tzdata` in your program—rather, `zoneinfo` uses it automatically.)

`zoneinfo` provides one class: `ZoneInfo`, a concrete implementation of the `datetime.tzinfo` abstract class. You can assign it to `tzinfo` during construction of an aware `datetime` instance, or use it with the `datetime.replace` or `datetime.astimezone` methods. To construct a `ZoneInfo`, use one of the defined IANA time zone names, such as `"America/Los_Angeles"` or `"Asia/Tokyo"`. You can get a list of these time zone names by calling `zoneinfo.available_timezones()`. More details on each time zone (such as offset from UTC and daylight savings information) can be found on Wikipedia.

Here are some examples using `ZoneInfo`. We'll start by getting the current local date and time in California:

```
>>> from datetime import datetime
>>> from zoneinfo import ZoneInfo
>>> d=datetime.now(tz=ZoneInfo("America/Los_Angeles"))
>>> d

datetime.datetime(2021,10,21,16,32,23,96782,tzinfo=zoneinfo.ZoneInfo(key
='America/Los_Angeles'))
```

3 Pre-3.9, use instead the third-party module `pytz`.

We can now update the time zone to a different one *without* changing other attributes (i.e., without converting the time to the new time zone):

```
>>> dny=d.replace(tzinfo=ZoneInfo("America/New_York"))
>>> dny
```

```
datetime.datetime(2021,10,21,16,32,23,96782,tzinfo=zoneinfo.ZoneInfo(key
='America/New_York'))
```

Convert a `datetime` instance to UTC:

```
>>> dutc=d.astimezone(tz=ZoneInfo("UTC"))
>>> dutc
```

```
datetime.datetime(2021,10,21,23,32,23,96782,tzinfo=zoneinfo.ZoneInfo(key
='UTC'))
```

Get an *aware* timestamp of the current time in UTC:

```
>>> daware=datetime.utcnow().replace(tzinfo=ZoneInfo("UTC"))
>>> daware
```

```
datetime.datetime(2021,10,21,23,32,23,96782,tzinfo=zoneinfo.ZoneInfo(key
='UTC'))
```

Display the `datetime` instance in a different time zone:

```
>>> dutc.astimezone(ZoneInfo("Asia/Katmandu")) # offset +5h 45m
```

```
datetime.datetime(2021,10,22,5,17,23,96782,tzinfo=zoneinfo.ZoneInfo(key
='Asia/Katmandu'))
```

Get the local time zone:

```
>>> tz_local=datetime.now().astimezone().tzinfo
>>> tz_local
```

```
datetime.timezone(datetime.timedelta(days=-1, seconds=61200), 'Pacific
Daylight Time')
```

Convert the UTC `datetime` instance back into the local time zone:

```
>>> dt_loc=dutc.astimezone(tz_local)
>>> dt_loc
```

```
datetime.datetime(2021, 10, 21, 16, 32, 23, 96782, tzinfo=datetime.time
(datetime.timedelta(days=-1, seconds=61200), 'Pacific Daylight Time'))
```

```
>>> d==dt_local
```

```
True
```

And get a sorted list of all available time zones:

```
>>> tz_list=zoneinfo.available_timezones()
>>> sorted(tz_list)[0],sorted(tz_list)[-1]
```

```
('Africa/Abidjan', 'Zulu')
```

Always Use the UTC Time Zone Internally

The best way to program around the traps and pitfalls of time zones is to always use the UTC time zone internally, converting from other time zones on input, and use `datetime.astimezone` only for display purposes.

This tip applies even if your application runs only in your own location, with no intention of ever using time data from other time zones. If your application runs continuously for days or weeks at a time, and the time zone configured for your system observes daylight savings time, you *will* run into time zone-related issues if you don't work in UTC internally.

The dateutil Module

The third-party package `dateutil` (which you can install with **`pip install python-dateutil`**) offers modules to manipulate dates in many ways. Table 13-10 lists the main modules it provides, in addition to those for time zone–related operations (now best performed with `zoneinfo`, discussed in the previous section).

Table 13-10. `dateutil` modules

`easter`	`easter.easter(`*`year`*`)`
	Returns the `datetime.date` object for Easter of the given *`year`*. For example:
	`>>> from dateutil import easter`
	`>>> print(easter.easter(2023))`
	`2023-04-09`

`parser`	`parser.parse(`*`s`*`)`
	Returns the `datetime.datetime` object denoted by string *`s`*, with very permissive (or "fuzzy") parsing rules. For example:
	`>>> from dateutil import parser`
	`>>> print(parser.parse('Saturday, January 28,'`
	`                        ' 2006, at 11:15pm'))`
	`2006-01-28 23:15:00`

`relativedelta`	`relativedelta.relativedelta(...)` Provides, among other things, an easy way to find "next Monday," "last year," etc. `dateutil`'s docs offer detailed explanations of the rules defining the inevitably complicated behavior of `relativedelta` instances.
`rrule`	`rrule.rrule(`*`freq`*`, ...)` Implements RFC 2445 (also known as the `iCalendar` RFC), in all the glory of its 140+ pages. `rrule` allows you to deal with recurring events, providing such methods as `after`, `before`, `between`, and `count`.

See the documentation for complete details on the `dateutil` module's rich functionality.

The sched Module

The `sched` module implements an event scheduler, letting you easily deal with events that may be scheduled in either a "real" or a "simulated" time scale. This event scheduler is safe to use in single and multithreaded environments. `sched` supplies a `scheduler` class that takes two optional arguments, `timefunc` and `delayfunc`.

`scheduler`	**`class`** `scheduler(timefunc=time.monotonic, delayfunc=time.sleep)` The optional argument `timefunc` must be callable without arguments to get the current time instant (in any unit of measure); for example, you can pass `time.time`. The optional `delayfunc` is callable with one argument (a time duration, in the same units as `timefunc`) to delay the current thread for that time. `scheduler` calls `delayfunc(0)` after each event to give other threads a chance; this is compatible with `time.sleep`. By taking functions as arguments, `scheduler` lets you use whatever "simulated time" or "pseudotime" fits your application's needs[a]. If monotonic time (time that cannot go backward even if the system clock is adjusted backward between calls, e.g., due to leap seconds) is critical to your application, use the default `time.monotonic` for your scheduler.

[a] A great example of the dependency injection design pattern for purposes not necessarily related to testing.

A `scheduler` instance *`s`* supplies the methods detailed in Table 13-11.

Table 13-11. Methods of an instance `s` of `scheduler`

`cancel`	*`s`*`.cancel(`*`event_token`*`)` Removes an event from *s*'s queue. *`event_token`* must be the result of a previous call to *`s`*`.enter` or *`s`*`.enterabs`, and the event must not yet have happened; otherwise, `cancel` raises `RuntimeError`.
`empty`	*`s`*`.empty()` Returns **`True`** when *s*'s queue is currently empty; otherwise, returns **`False`**.

`enter`	*`s`*`.enter(`*`delay`*`, `*`priority`*`, `*`func`*`, argument=(), kwargs={})`
	Like `enterabs`, except that *`delay`* is a relative time (a positive difference forward from the current instant), while `enterabs`'s argument *when* is an absolute time (a future instant). To schedule an event for *repeated* execution, use a little wrapper function; for example:
	`def enter_repeat(s, first_delay, period, priority,`
	`        func, args):`
	`    def repeating_wrapper():`
	`        s.enter(period, priority,`
	`                repeating_wrapper, ())`
	`        func(*args)`
	`    s.enter(first_delay, priority,`
	`        repeating_wrapper, args)`

`enterabs`	`s.enterabs(when, priority, func, argument=(), kwargs={})` Schedules a future event (a callback to `func(args, kwargs)`) at time *when*. *when* is in the units used by the time functions of *s*. Should several events be scheduled for the same time, *s* executes them in increasing order of *priority*. `enterabs` returns an event token *t*, which you may later pass to `s.cancel` to cancel this event.
`run`	`s.run(blocking=True)` Runs scheduled events. If `blocking` is **`True`**, `s.run` loops until `s.empty` returns **`True`**, using the `delayfunc` passed on *s*'s initialization to wait for each scheduled event. If `blocking` is **`False`**, executes any soon-to-expire events, then returns the next event's deadline (if any). When a callback *func* raises an exception, *s* propagates it, but *s* keeps its own state, removing the event from the schedule. If a callback *func* runs longer than the time available before the next scheduled event, *s* falls behind but keeps executing scheduled events in order, never dropping any. Call `s.cancel` to drop an event explicitly if that event is no longer of interest.

The calendar Module

The `calendar` module supplies calendar-related functions, including functions to print a text calendar for a given month or year. By default, `calendar` takes Monday as the first day of the week and Sunday as the last one. To change this, call `calendar.setfirstweekday`. `calendar` handles years in module `time`'s range, typically (at least) 1970 to 2038.

The `calendar` module supplies the functions listed in Table 13-12.

Table 13-12. Functions of the `calendar` module

`calendar`	`calendar(year, w=2, li=1, c=6)` Returns a multiline string with a calendar for year *year* formatted into three columns separated by `c` spaces. `w` is the width in characters of each date; each line has length `21*w+18+2*c`. `li` is the number of lines for each week.
`firstweekday`	`firstweekday()` Returns the current setting for the weekday that starts each week. By default, when `calendar` is first imported, this is `0` (meaning Monday).
`isleap`	`isleap(year)` Returns **`True`** if *year* is a leap year; otherwise, returns **`False`**.
`leapdays`	`leapdays(y1, y2)` Returns the total number of leap days in the years within `range(y1, y2)` (remember, this means that *y2* is excluded).
`month`	`month(year, month, w=2, li=1)` Returns a multiline string with a calendar for month *month* of year *year*, one line per week plus two header lines. `w` is the width in characters of each date; each line has length `7*w+6`. `li` is the number of lines for each week.

monthcalendar	monthcalendar(*year*, *month*) Returns a list of lists of ints. Each sublist denotes a week. Days outside month *month* of year *year* are set to 0; days within the month are set to their day of month, 1 and up.
monthrange	monthrange(*year*, *month*) Returns two integers. The first one is the code of the weekday for the first day of the month *month* in year *year*; the second one is the number of days in the month. Weekday codes are 0 (Monday) to 6 (Sunday); month numbers are 1 to 12.
prcal	prcal(*year*, w=2, li=1, c=6) Like print(calendar.calendar(*year*, *w*, *li*, *c*)).
prmonth	prmonth(*year*, *month*, w=2, li=1) Like print(calendar.month(*year*, *month*, *w*, *li*)).
setfirstweekday	setfirstweekday(*weekday*) Sets the first day of each week to weekday code *weekday*. Weekday codes are 0 (Monday) to 6 (Sunday). calendar supplies the attributes MONDAY, TUESDAY, WEDNESDAY, THURSDAY, FRIDAY, SATURDAY, and SUNDAY, whose values are the integers 0 to 6. Use these attributes when you mean weekdays (e.g., calendar.FRIDAY instead of 4) to make your code clearer and more readable.
timegm	timegm(*tupletime*) Just like time.mktime: accepts a time instant in timetuple form and returns that instant as a float number of seconds since the epoch.
weekday	weekday(*year*, *month*, *day*) Returns the weekday code for the given date. Weekday codes are 0 (Monday) to 6 (Sunday); month numbers are 1 (January) to 12 (December).

python -m calendar offers a useful command-line interface to the module's functionality: run **python -m calendar -h** to get a brief help message.

14 Customizing Execution

Python exposes, supports, and documents many of its internal mechanisms. This may help you understand Python at an advanced level, and lets you hook your own code into such Python mechanisms, controlling them to some extent. For example, "Python built-ins" on page 224 covers the way Python arranges for built-ins to be visible. This chapter covers some other advanced Python techniques, including site customization, termination functions, dynamic execution, handling internal types, and garbage collection. We'll look at other issues related to controlling execution using multiple threads and processes in Chapter 15; Chapter 17 covers issues specific to testing, debugging, and profiling.

Per-Site Customization

Python provides a specific "hook" to let each site customize some aspects of Python's behavior at the start of each run. Python loads the standard module `site` just before the main script. If Python is run with the option **`-S`**, it does not load `site`. **`-S`** allows faster startup but saddles the main script with initialization chores. `site`'s tasks are, chiefly, to put `sys.path` in standard form (absolute paths, no duplicates), including as directed by environment variables, by virtual environments, and by each *.pth* file found in a directory in `sys.path`.

Secondarily, if the session starting is an interactive one, `site` adds several handy built-ins (such as `exit`, `copyright`, etc.) and, if `readline` is enabled, configure autocompletion as the function of the Tab key.

In any normal Python installation, the installation process sets everything up to ensure that `site`'s work is sufficient to let Python programs and interactive sessions run "normally," i.e., as they would on any other system with that version of Python installed. In exceptional cases, if as a system administrator (or in an equivalent role, such as a user who has installed Python in their home directory for their sole use) you think you absolutely need to do some customization, perform it in a new file called *sitecustomize.py* (create it in the same directory where *site.py* lives).

> **Avoid Modifying site.py**
>
> We strongly recommend that you do *not* alter the *site.py* file that performs the base customization. Doing so might cause Python to behave differently on your system than elsewhere. In any case, the *site.py* file will be overwritten each and every time you update your Python installation, and your modifications will be lost.

In the rare cases where *sitecustomize.py* is present, what it typically does is add yet more dictionaries to `sys.path`—the best way to perform this task is for *sitecustomize.py* to **`import`** `site` and then to call `site.addsitedir(`*`path_to_a_dir`*`)`.

Termination Functions

The `atexit` module lets you register termination functions (i.e., functions to be called at program termination, in LIFO order). Termination functions are similar to cleanup handlers established by **`try`**/**`finally`** or **`with`**. However, termination functions are globally registered and get called at the end of the whole program, while cleanup handlers are established lexically and get called at the end of a specific **`try`** clause or **`with`** statement. Termination functions and cleanup handlers are called whether the program terminates normally or abnormally, but not when the program ends by calling `os._exit` (so you normally call `sys.exit` instead). The `atexit` module supplies a function called `register` that takes as arguments *`func`*, *`*args`*, and *`*kwds`* and ensures that *`func`*`(`*`*args`*`, `*`**kwds`*`)` is called at program termination time.

Dynamic Execution and exec

Python's `exec` built-in function can execute code that you read, generate, or otherwise obtain during a program's run. `exec` dynamically executes a statement or a suite of statements. It has the following syntax:

```
exec(code, globals=None, locals=None, /)
```

`code` can be a `str`, `bytes`, `bytearray`, or code object. *`globals`* is a `dict`, and *`locals`* can be any mapping.

If you pass both *`globals`* and *`locals`*, they are the global and local namespaces in which *`code`* runs. If you pass only *`globals`*, `exec` uses *`globals`* as both namespaces. If you pass neither, *`code`* runs in the current scope.

> **Never Run exec in the Current Scope**
>
> Running `exec` in the current scope is a particularly bad idea: it can bind, rebind, or unbind any global name. To keep things under control, use `exec`, if at all, only with specific, explicit dictionaries.

Avoiding exec

A frequently asked question about Python is "How do I set a variable whose name I just read or built?" Literally, for a *global* variable, `exec` allows this, but it's a very bad idea to use `exec` for this purpose. For example, if the name of the variable is in *`varname`*, you might think to use:

```
exec(varname + ' = 23')
```

Don't do this. An `exec` like this in the current scope makes you lose control of your namespace, leading to bugs that are extremely hard to find and making your program unfathomably difficult to understand. Keep the "variables" that you need to set with dynamically found names not as actual variables, but as entries in a dictionary (say, *`mydict`*). You might then consider using:

```
exec(varname+'=23', mydict) # Still a bad idea
```

While this is not quite as terrible as the previous example, it is still a bad idea. Keeping such "variables" as dictionary entries means that you don't have any need to use `exec` to set them! Just code:

```
mydict[varname] = 23
```

This way, your program is clearer, direct, elegant, and faster. There *are* some valid uses of `exec`, but they are extremely rare: just use explicit dictionaries instead.

> **Strive to Avoid exec**
>
> Use `exec` only when it's really indispensable, which is *extremely* rare. Most often, it's best to avoid `exec` and choose more specific, well-controlled mechanisms: `exec` weakens your control of your code's namespace, can damage your program's performance, and exposes you to numerous hard-to-find bugs and huge security risks.

Expressions

`exec` can execute an expression, because any expression is also a valid statement (called an *expression statement*). However, Python ignores the value returned by an expression statement. To evaluate an expression and obtain the expression's value, use the built-in function `eval`, covered in Table 8-2. (Note, however, that just about all of the same security risk caveats for `exec` also apply to `eval`.)

compile and Code Objects

To make a code object to use with `exec`, call the built-in function `compile` with the last argument set to `'exec'` (as covered in Table 8-2).

A code object *c* exposes many interesting read-only attributes whose names all start with `'co_'`, such as those listed in Table 14-1.

Table 14-1. Read-only attributes of code objects

`co_argcount`	The number of parameters of the function of which *c* is the code (`0` when *c* is not the code object of a function, but rather is built directly by `compile`)
`co_code`	A `bytes` object with *c*'s bytecode
`co_consts`	The tuple of constants used in *c*
`co_filename`	The name of the file *c* was compiled from (the string that is the second argument to `compile`, when *c* was built that way)
`co_first lineno`	The initial line number (within the file named by `co_filename`) of the source code that was compiled to produce *c*, if *c* was built by compiling from a file
`co_name`	The name of the function of which *c* is the code (`'<module>'` when *c* is not the code object of a function but rather is built directly by `compile`)
`co_names`	The tuple of all identifiers used within *c*
`co_varnames`	The tuple of local variables' identifiers in *c*, starting with parameter names

Most of these attributes are useful only for debugging purposes, but some may help with advanced introspection, as exemplified later in this section.

If you start with a string holding one or more statements, first use `compile` on the string, then call `exec` on the resulting code object—that's a bit better than giving `exec` the string to compile and execute. This separation lets you check for syntax errors separately from execution-time errors. You can often arrange things so that the string is compiled once and the code object executes repeatedly, which speeds things up. `eval` can also benefit from such separation. Moreover, the `compile` step is intrinsically safe (both `exec` and `eval` are extremely risky if you execute them on code that you don't 100% trust), and you may be able to check the code object before it executes, to lessen the risk (though it will never truly be zero).

As mentioned in Table 14-1, a code object has a read-only attribute `co_names` that is the tuple of the names used in the code. For example, say that you want the user to enter an expression that contains only literal constants and operators—no function calls or other names. Before evaluating the expression, you can check that the string the user entered satisfies these constraints:

```
def safer_eval(s):
    code = compile(s, '<user-entered string>', 'eval')
    if code.co_names:
        raise ValueError(
```

```
            f'Names {code.co_names!r} not allowed in expression {s!r}')
    return eval(code)
```

This function `safer_eval` evaluates the expression passed in as argument *s* only when the string is a syntactically valid expression (otherwise, `compile` raises `SyntaxError`) and contains no names at all (otherwise, `safer_eval` explicitly raises `ValueError`). (This is similar to the standard library function `ast.literal_eval`, covered in "Standard Input" on page 370, but a bit more powerful, since it does allow the use of operators.)

Knowing what names the code is about to access may sometimes help you optimize the preparation of the dictionary that you need to pass to `exec` or `eval` as the namespace. Since you need to provide values only for those names, you may save work by not preparing other entries. For example, say that your application dynamically accepts code from the user, with the convention that variable names starting with `data_` refer to files residing in the subdirectory *data* that user-written code doesn't need to read explicitly. User-written code may, in turn, compute and leave results in global variables with names starting with `result_`, which your application writes back as files in the *data* subdirectory. Thanks to this convention, you may later move the data elsewhere (e.g., to BLOBs in a database instead of files in a subdirectory), and user-written code won't be affected. Here's how you might implement these conventions efficiently:

```
def exec_with_data(user_code_string):
    user_code = compile(user_code_string, '<user code>', 'exec')
    datadict = {}
    for name in user_code.co_names:
        if name.startswith('data_'):
            with open(f'data/{name[5:]}', 'rb') as datafile:
                datadict[name] = datafile.read()
        elif name.startswith('result_'):
            pass  # user code assigns to variables named `result_...`
        else:
            raise ValueError(f'invalid variable name {name!r}')
    exec(user_code, datadict)
    for name in datadict:
        if name.startswith('result_'):
            with open(f'data/{name[7:]}', 'wb') as datafile:
                datafile.write(datadict[name])
```

Never exec or eval Untrusted Code

Some older versions of Python supplied tools that aimed to ameliorate the risks of using `exec` and `eval`, under the heading of "restricted execution," but those tools were never entirely secure against the ingenuity of able hackers, and recent versions of Python have dropped them to avoid offering the user an unfounded sense of security. If you need to guard against such attacks, take advantage of your operating system's protection mechanisms: run untrusted code in a separate process, with privileges as restricted as you can possibly make them (study the mechanisms that your OS supplies for the purpose, such as `chroot`, `setuid`, and `jail`; in Windows, you might try the third-party commercial add-on WinJail, or run untrusted code in a separate, highly constrained virtual machine or container, if you're an expert on how to securitize containers). To guard against denial of service attacks, have the main process monitor the separate one and terminate the latter if and when resource consumption becomes excessive. Processes are covered in "Running Other Programs" on page 476.

> **exec and eval Are Unsafe with Untrusted Code**
>
> The function `exec_with_data` defined in the previous section is not at all safe against untrusted code: if you pass to it, as the argument *`user_code`*, some string obtained in a way that you cannot *entirely* trust, there is essentially no limit to the amount of damage it might do. This is unfortunately true of just about any use of `exec` or `eval`, except for those rare cases in which you can set extremely strict and fully checkable limits on the code to execute or evaluate, as was the case for the function `safer_eval`.

Internal Types

Some of the internal Python objects described in this section are hard to use, and indeed are not meant for you to use most of the time. Using such objects correctly and to good effect requires some study of your Python implementation's C sources. Such black magic is rarely needed, except for building general-purpose development tools and similar wizardly tasks. Once you do understand things in depth, Python empowers you to exert control if and when needed. Since Python exposes many kinds of internal objects to your Python code, you can exert that control by coding in Python, even when you need an understanding of C to read Python's sources and understand what's going on.

Type Objects

The built-in type named `type` acts as a callable factory, returning objects that are types. Type objects don't have to support any special operations except equality comparison and representation as strings. However, most type objects are callable and return new instances of the type when called. In particular, built-in types such as `int`, `float`, `list`, `str`, `tuple`, `set`, and `dict` all work this way; specifically, when called without arguments, they return a new empty instance, or, for numbers, one that equals `0`. The attributes of the `types` module are the built-in types that don't have built-in names. Besides being callable to generate instances, type objects are useful because you can inherit from them, as covered in "Classes and Instances" on page 115.

The Code Object Type

Besides using the built-in function `compile`, you can get a code object via the `__code__` attribute of a function or method object. (For a discussion of the attributes of code objects, see "compile and Code Objects" on page 432.) Code objects are not callable, but you can rebind the `__code__` attribute of a function object with the right number of parameters in order to wrap a code object into callable form. For example:

```
def g(x):
    print('g', x)
code_object = g.__code__
def f(x):
    pass
f.__code__ = code_object
f(23)     # prints: g 23
```

Code objects that have no parameters can also be used with `exec` or `eval`. Directly creating code objects requires many parameters; see Stack Overflow's unofficial docs on how to do it (but bear in mind that you're usually better off calling `compile` instead).

The Frame Type

The function `_getframe` in the module `sys` returns a frame object from Python's call stack. A frame object has attributes giving information about the code executing in the frame and the execution state. The `traceback` and `inspect` modules help you access and display such information, particularly when an exception is being handled. Chapter 17 provides more information about frames and tracebacks, and covers the module `inspect`, which is the best way to perform such introspection. As the leading underscore in the name `_getframe` hints, the function is "somewhat private"; it's meant for use only by tools such as debuggers, which inevitably require deep introspection into Python's internals.

Garbage Collection

Python's garbage collection normally proceeds transparently and automatically, but you can choose to exert some direct control. The general principle is that Python collects each object *x* at some time after *x* becomes unreachable—that is, when no chain of references can reach *x* by starting from a local variable of a function instance that is executing, or from a global variable of a loaded module. Normally, an object *x* becomes unreachable when there are no references at all to *x*. In addition, a group of objects can be unreachable when they reference each other but no global or local variables reference any of them, even indirectly (such a situation is known as a *mutual reference loop*).

Classic Python keeps with each object *x* a count, known as a *reference count*, of how many references to *x* are outstanding. When *x*'s reference count drops to

0, CPython immediately collects *x*. The function getrefcount of the module sys accepts any object and returns its reference count (at least 1, since getrefcount itself has a reference to the object it's examining). Other versions of Python, such as Jython or PyPy, rely on other garbage collection mechanisms supplied by the platform they run on (e.g., the JVM or the LLVM). The modules gc and weakref, therefore, apply only to CPython.

When Python garbage-collects *x* and there are no references to *x*, Python finalizes *x* (i.e., calls *x*.__del__) and frees the memory that *x* occupied. If *x* held any references to other objects, Python removes the references, which in turn may make other objects collectable by leaving them unreachable.

The gc Module

The gc module exposes the functionality of Python's garbage collector. gc deals with unreachable objects that are part of mutual reference loops. As mentioned previously, in such a loop, each object in the loop refers to one or more of the others, keeping the reference counts of all the objects positive, but there are no outside references to any of the set of mutually referencing objects. Therefore, the whole group, also known as *cyclic garbage*, is unreachable and thus garbage-collectable. Looking for such cyclic garbage loops takes time, which is why the module gc exists: to help you control whether and when your program spends that time. By default, cyclic garbage collection functionality is enabled with some reasonable default parameters: however, by importing the gc module and calling its functions, you may choose to disable the functionality, change its parameters, and/or find out exactly what's going on in this respect.

gc exposes attributes and functions to help you manage and instrument cyclic garbage collection, including those listed in Table 14-2. These functions can let you track down memory leaks—objects that are not collected even though there *should* be no more references to them—by helping you discover what other objects are in fact holding on to references to them. Note that gc implements the architecture known in computer science as generational garbage collection.

Table 14-2. gc functions and attributes

callbacks	A list of callbacks that the garbage collector will invoke before and after collection. See "Instrumenting garbage collection" on page 439 for further details.
collect	collect() Forces a full cyclic garbage collection run to happen immediately.
disable	disable() Suspends automatic, periodic cyclic garbage collection.
enable	enable() Reenables periodic cyclic garbage collection previously suspended with disable.

`freeze`	`freeze()` Freezes all objects tracked by `gc`: moves them to a "permanent generation," i.e., a set of objects to be ignored in all the future collections.
`garbage`	A `list` (but, treat it as read-only) of unreachable but uncollectable objects. This happens when any object in a cyclic garbage loop has a `__del__` special method, as there may be no demonstrably safe order for Python to finalize such objects.
`get_count`	`get_count()` Returns the current collection counts as a tuple, `(count0, count1, count2)`.
`get_debug`	`get_debug()` Returns an `int` bit string, the garbage collection debug flags set with `set_debug`.
`get_freeze_count`	`get_freeze_count()` Returns the number of objects in the permanent generation.
`get_objects`	`get_objects(generation=`**`None`**`)` Returns a list of objects being tracked by the collector. **3.8+** If the optional `generation` argument is not **`None`**, lists only those objects in the selected generation.
`get_referents`	`get_referents(`*`*objs`*`)` Returns a list of objects, visited by the arguments' C-level `tp_traverse` methods, that are referred to by any of the arguments.
`get_referrers`	`get_referrers(`*`*objs`*`)` Returns a list of all container objects currently tracked by the cyclic garbage collector that refer to any one or more of the arguments.
`get_stats`	`get_stats()` Returns a list of three `dicts`, one per generation, containing counts of the number of collections, the number of objects collected, and the number of uncollectable objects.
`get_threshold`	`get_threshold()` Returns the current collection thresholds as a tuple of the three `ints`.
`isenabled`	`isenabled()` Returns **`True`** when cyclic garbage collection is currently enabled; otherwise returns **`False`.**
`is_finalized`	`is_finalized(`*`obj`*`)` **3.9+** Returns **`True`** when the garbage collector has finalized *`obj`*; otherwise, returns **`False`**.
`is_tracked`	`is_tracked(`*`obj`*`)` Returns **`True`** when *`obj`* is currently tracked by the garbage collector; otherwise, returns **`False`**.

`set_debug`	`set_debug(`*`flags`*`)`
	Sets flags for debugging behavior during garbage collection. *`flags`* is an `int`, interpreted as a bit string, built by ORing (with the bitwise OR operator, `|`) zero or more constants supplied by the module `gc`. Each bit enables a specific debugging function:
	
	`DEBUG_COLLECTABLE`
	Prints information on collectable objects found during garbage collection.
	
	`DEBUG_LEAK`
	Combines behavior for `DEBUG_COLLECTABLE, DEBUG_UNCOLLECTABLE`, and `DEBUG_SAVEALL`. Together, these are the most common flags used to help you diagnose memory leaks.
	
	`DEBUG_SAVEALL`
	Saves all collectable objects to the list `gc.garbage` (where uncollectable ones are also always saved) to help you diagnose leaks.
	
	`DEBUG_STATS`
	Prints statistics gathered during garbage collection to help you tune the thresholds.
	
	`DEBUG_UNCOLLECTABLE`
	Prints information on uncollectable objects found during garbage collection.

`set_threshold`	`set_threshold(`*`thresh0`*`[,` *`thresh1`*`[,` *`thresh2`*`]])` Sets thresholds that control how often cyclic garbage collection cycles run. A *`thresh0`* of `0` disables garbage collection. Garbage collection is an advanced, specialized topic, and the details of the generational garbage collection approach used in Python (and consequently the detailed meanings of these thresholds) are beyond the scope of this book; see the online docs for details.
`unfreeze`	`unfreeze()` Unfreezes all objects in the permanent generation, moving them all back to the oldest generation.

When you know there are no cyclic garbage loops in your program, or when you can't afford the delay of cyclic garbage collection at some crucial time, suspend automatic garbage collection by calling `gc.disable()`. You can enable collection again later by calling `gc.enable()`. You can test whether automatic collection is currently enabled by calling `gc.isenabled()`, which returns **`True`** or **`False`**. To control *when* time is spent collecting, you can call `gc.collect()` to force a full cyclic collection run to happen immediately. To wrap some time-critical code:

```
import gc
gc_was_enabled = gc.isenabled()
if gc_was_enabled:
    gc.collect()
    gc.disable()
```

```
    # insert some time-critical code here
    if gc_was_enabled:
        gc.enable()
```

You may find this easier to use if implemented as a context manager:

```
import gc
import contextlib

@contextlib.contextmanager
def gc_disabled():
    gc_was_enabled = gc.isenabled()
    if gc_was_enabled:
        gc.collect()
        gc.disable()
    try:
        yield
    finally:
        if gc_was_enabled:
            gc.enable()

with gc_disabled():
    # ...insert some time-critical code here...
```

Other functionality in the module `gc` is more advanced and rarely used, and can be grouped into two areas. The functions `get_threshold` and `set_threshold` and debug flag `DEBUG_STATS` help you fine-tune garbage collection to optimize your program's performance. The rest of `gc`'s functionality can help you diagnose memory leaks in your program. While `gc` itself can automatically fix many leaks (as long as you avoid defining `__del__` in your classes, since the existence of `__del__` can block cyclic garbage collection), your program runs faster if it avoids creating cyclic garbage in the first place.

Customizing Execution

Instrumenting garbage collection

`gc.callbacks` is an initially empty list to which you can add functions `f(`*`phase`*`,` *`info`*`)` which Python is to call upon garbage collection. When Python calls each such function, *`phase`* is `'start'` or `'stop'` to mark the beginning or end of a collection, and *`info`* is a dictionary containing information about the generational collection used by CPython. You can add functions to this list, for example to gather statistics about garbage collection. See the documentation for more details.

The weakref Module

Careful design can often avoid reference loops. However, at times you need objects to know about each other, and avoiding mutual references would distort and complicate your design. For example, a container has references to its items, yet it can often be useful for an object to know about a container holding it. The result is a reference loop: due to the mutual references, the container and items keep each other alive, even when all other objects forget about them. Weak references solve this problem by allowing objects to reference others without keeping them alive.

A *weak reference* is a special object `w` that refers to some other object `x` without incrementing *x*'s reference count. When *x*'s reference count goes down to `0`, Python finalizes and collects `x`, then informs `w` of *x*'s demise. Weak reference `w` can now either disappear or get marked as invalid in a controlled way. At any time, a given `w` refers to either the same object `x` as when `w` was created, or to nothing at all; a weak reference is never retargeted. Not all types of objects support being the target `x` of a weak reference `w`, but classes, instances, and functions do.

The `weakref` module exposes functions and types to create and manage weak references, detailed in Table 14-3.

Table 14-3. Functions and classes of the `weakref` module

`getweakref count`	`getweakrefcount(`*x*`)` Returns `len(getweakrefs(`*x*`))`.
`getweakrefs`	`getweakrefs(`*x*`)` Returns a list of all weak references and proxies whose target is *x*.
`proxy`	`proxy(`*x*`[,` *f*`])` Returns a weak proxy *p* of type `ProxyType` (`CallableProxyType` when *x* is callable) with *x* as the target. Using *p* is just like using *x*, except that, when you use *p* after *x* has been deleted, Python raises `ReferenceError`. *p* is never hashable (you cannot use *p* as a dictionary key). When *f* is present, it must be callable with one argument, and is the finalization callback for *p* (i.e., right before finalizing *x*, Python calls *f*`(`*p*`)`).) *f* executes right *after* *x* is no longer reachable from *p*.
`ref`	`ref(`*x*`[,` *f*`])` Returns a weak reference *w* of type `ReferenceType` with object *x* as the target. *w* is callable without arguments: calling *w*`()` returns *x* when *x* is still alive; otherwise, *w*`()` returns `None`. *w* is hashable when *x* is hashable. You can compare weak references for equality (==, !=), but not for order (<, >, <=, >=). Two weak references *x* and *y* are equal when their targets are alive and equal, or when *x* is *y*. When *f* is present, it must be callable with one argument and is the finalization callback for *w* (i.e., right before finalizing *x*, Python calls *f*`(`*w*`)`). *f* executes right *after* *x* is no longer reachable from *w*.
`WeakKey Dictionary`	`class WeakKeyDictionary(adict={})` A `WeakKeyDictionary` *d* is a mapping weakly referencing its keys. When the reference count of a key *k* in *d* goes to `0`, item *d*`[`*k*`]` disappears. `adict` is used to initialize the mapping.
`WeakSet`	class WeakSet(elements=[]) A `WeakSet` *s* is a set weakly referencing its content elements, initialized from `elements`. When the reference count of an element *e* in *s* goes to `0`, *e* disappears from *s*.
`WeakValue Dictionary`	`class WeakValueDictionary(adict={})` A `WeakValueDictionary` *d* is a mapping weakly referencing its values. When the reference count of a value *v* in *d* goes to `0`, all items of *d* such that *d*`[`*k*`]` **`is`** *v* disappear. `adict` is used to initialize the mapping.

`WeakKeyDictionary` lets you noninvasively associate additional data with some hashable objects, with no change to the objects. `WeakValueDictionary` lets you noninvasively record transient associations between objects, and build caches. In each case, use a weak mapping, rather than a `dict`, to ensure that an object that is otherwise garbage-collectable is not kept alive just by being used in a mapping. Similarly, a `WeakSet` provides the same weak containment functionality in place of a normal `set`.

A typical example is a class that keeps track of its instances, but does not keep them alive just to keep track of them:

```
import weakref
class Tracking:
    _instances_dict = weakref.WeakValueDictionary()

    def __init__(self):
        Tracking._instances_dict[id(self)] = self

    @classmethod
    def instances(cls):
        return cls._instances_dict.values()
```

When the `Tracking` instances are hashable, a similar class can be implemented using a `WeakSet` of the instances, or a `WeakKeyDictionary` with the instances as keys and **`None`** for the values.

15 Concurrency: Threads and Processes

Processes are instances of running programs that the operating system protects from one another. Processes that want to communicate must explicitly arrange to do so via *interprocess communication* (IPC) mechanisms, and/or via files (covered in Chapter 11), databases (covered in Chapter 12), or network interfaces (covered in Chapter 18). The general way in which processes communicate using data storage mechanisms such as files and databases is that one process writes data, and another process later reads that data back. This chapter covers programming with processes, including the Python standard library modules `subprocess` and `multiprocessing`; the process-related parts of the module `os`, including simple IPC by means of *pipes*; a cross-platform IPC mechanism known as *memory-mapped files*, available in the module `mmap`; **3.8+** and the `multiprocessing.shared_memory` module.

A *thread* (originally called a "lightweight process") is a flow of control that shares global state (memory) with other threads inside a single process; all threads appear to execute simultaneously, although they may in fact be "taking turns" on one or more processors/cores. Threads are far from easy to master, and multithreaded programs are often hard to test and to debug; however, as covered in "Threading, Multiprocessing, or Async Programming?" on page 445, when used appropriately, multithreading may improve performance in comparison to single-threaded programming. This chapter covers various facilities Python provides for dealing with threads, including the `threading`, `queue`, and `concurrent.futures` modules.

Another mechanism for sharing control among multiple activities within a single process is what has become known as *asynchronous* (or *async*) programming. When you are reading Python code, the presence of the keywords **`async`** and **`await`** indicate it is asynchronous. Such code depends on an *event loop*, which is, broadly speaking, the equivalent of the thread switcher used within a process. When the event loop is the scheduler, each execution of an asynchronous function becomes a *task*, which roughly corresponds with a *thread* in a multithreaded program.

Both process scheduling and thread switching are *preemptive*, which is to say that the scheduler or switcher has control of the CPU and determines when any particular piece of code gets to run. Asynchronous programming, however, is *cooperative*: each task, once execution begins, can run for as long as it chooses before indicating to the event loop that it is prepared to give up control (usually because it is awaiting the completion of some other asynchronous task, most often an I/O-focused one).

Although async programming offers great flexibility to optimize certain classes of problems, it is a programming paradigm that many programmers are unfamiliar with. Because of its cooperative nature, incautious async programming can lead to *deadlocks*, and infinite loops can starve other tasks of processor time: figuring out how to avoid deadlocks creates significant extra cognitive load for the average programmer. We do not cover asynchronous programming, including the module `asyncio`, further in this volume, feeling that it is a complex enough topic to be well worth a book on its own.[1]

Network mechanisms are well suited for IPC, and work just as effectively between processes running on different nodes of a network as between ones that run on the same node. The `multiprocessing` module supplies some mechanisms that are suitable for IPC over a network; Chapter 18 covers low-level network mechanisms that provide a basis for IPC. Other, higher-level mechanisms for *distributed computing* (CORBA, DCOM/COM+, EJB, SOAP, XML-RPC, .NET, gRPC, etc.) can make IPC a bit easier, whether locally or remotely; however, we do not cover distributed computing in this book.

When multiprocessor computers arrived, the OS had to deal with more complex scheduling problems, and programmers who wanted maximum performance had to write their applications so that code could truly be executed in parallel, on different processors or cores (from the programming point of view, cores are simply processors implemented on the same piece of silicon). This requires both knowledge and discipline. The CPython implementation simplifies these issues by implementing a *global interpreter lock* (GIL). In the absence of any action by the Python programmer, on CPython only the thread that holds the GIL is allowed access to the processor, effectively barring CPython processes from taking full advantage of multiprocessor hardware. Libraries such as NumPy, which are typically required to undertake lengthy computations of compiled code that uses none of the interpreter's facilities, arrange for their code to release the GIL during such computations. This

1 The best introductory work on async programming we have come across, though sadly now dated (as the async approach in Python keeps improving), is *Using Asyncio in Python*, by Caleb Hattingh (O'Reilly). We recommend you also study Brad Solomon's Asyncio walkthrough on Real Python.

allows effective use of multiple processors, but it isn't a technique that you can use if all your code is in pure Python.

Threading, Multiprocessing, or Async Programming?

In many cases, the best answer is "none of the above!" Each of these approaches is, at best, an optimization, and (as covered in "Optimization" on page 541) optimization is often unneeded, or at least premature. Each such approach can be prone to bugs and hard to test and debug; stick with single threading as long as you possibly can, and keep things simple.

When you *do* need optimization, and your program is *I/O-bound* (meaning that it spends much time doing I/O), async programming is fastest, as long as you can make your I/O operations *nonblocking* ones. Second best, when your I/O absolutely *has* to be blocking, the `threading` module can help an I/O-bound program's performance.

When your program is *CPU-bound* (meaning that it spends much time performing computations), in CPython `threading` usually does not help performance. This is because the GIL ensures that only one Python-coded thread at a time can execute (this also applies to PyPy). C-coded extensions can "release the GIL" while they're doing a time-consuming operation; NumPy (covered in Chapter 16) does so for array operations, for example. As a consequence, if your program is CPU-bound via calls to lengthy CPU operations in NumPy or other similarly optimized C-coded extension, the `threading` module may help your program's performance on a multiprocessor computer (as most computers are today).

When your program is CPU-bound via pure Python code and you're using CPython or PyPy on a multiprocessor computer, the `multiprocessing` module may help performance by allowing truly parallel computation. To solve problems across multiple network-connected computers (implementing distributed computing), however, you should look at the more specialized approaches and packages discussed on the Python wiki, which we don't cover in this book.

Threads in Python

Python supports multithreading on platforms that support threads, such as Windows, Linux, and just about all variants of Unix (including macOS). An action is known as *atomic* when it's guaranteed that no thread switching occurs between the start and the end of the action. In practice, in CPython, operations that *look* atomic (e.g., simple assignments and accesses) mostly *are* atomic, but only when executed on built-in types (augmented and multiple assignments, however, aren't atomic). Mostly, though, it's *not* a good idea to rely on such "atomicity." You might be dealing with an instance of a user-coded class rather than of a built-in type, in which there might be implicit calls to Python code that invalidate assumptions of atomicity. Further, relying on implementation-dependent atomicity may lock your code into a specific implementation, hampering future changes. You're better-advised to use the synchronization facilities covered in the rest of this chapter, rather than relying on atomicity assumptions.

The key design issue in multithreading systems is how best to coordinate multiple threads. The `threading` module, covered in the following section, supplies several synchronization objects. The `queue` module (discussed in "The queue Module" on page 456) is also very useful for thread synchronization: it supplies synchronized, thread-safe queue types, handy for communication and coordination between threads. The package `concurrent` (covered in "The concurrent.futures Module" on page 468) supplies a unified interface for communication and coordination that can be implemented by pools of either threads or processes.

The threading Module

The `threading` module supplies multithreading functionality. The approach of `threading` is to model locks and conditions as separate objects (in Java, for example, such functionality is part of every object), and threads cannot be directly controlled from the outside (thus, no priorities, groups, destruction, or stopping). All methods of objects supplied by `threading` are atomic.

`threading` supplies the following thread-focused classes, all of which we'll explore in this section: `Thread`, `Condition`, `Lock`, `RLock`, `Event`, `Semaphore`, `BoundedSemaphore`, `Timer`, and `Barrier`.

`threading` also supplies a number of useful functions, including those listed in Table 15-1.

Table 15-1. Functions of the `threading` module

`active_count`	`active_count()` Returns an `int`, the number of `Thread` objects currently alive (not ones that have terminated or not yet started).
`current_thread`	`current_thread()` Returns a `Thread` object for the calling thread. If the calling thread was not created by `threading`, `current_thread` creates and returns a semi-dummy `Thread` object with limited functionality.
`enumerate`	`enumerate()` Returns a `list` of all `Thread` objects currently alive (not ones that have terminated or not yet started).
`excepthook`	`excepthook(args)` **3.8+** Override this function to determine how in-thread exceptions are handled; see the online docs for details. The `args` argument has attributes that allow you to access exception and thread details. **3.10+** `threading.__excepthook__` holds the module's original `threadhook` value.

`get_ident`	`get_ident()` Returns a nonzero `int` as a unique identifier among all current threads. Useful to manage and track data by thread. Thread identifiers may be reused as threads exit and new threads are created.
`get_native_id`	`get_native_id()` **3.8+** Returns the native integer ID of the current thread as assigned by the operating system kernel. Available on most common operating systems.
`stack_size`	`stack_size([`*`size`*`])` Returns the current stack size, in bytes, used for new threads, and (when *`size`* is provided) establishes the value for new threads. Acceptable values for *`size`* are subject to platform-specific constraints, such as being at least `32768` (or an even higher minimum, on some platforms), and (on some platforms) being a multiple of `4096`. Passing *`size`* as `0` is always acceptable and means "use the system's default." When you pass a value for *`size`* that is not acceptable on the current platform, `stack_size` raises a `ValueError` exception.

Thread Objects

A `Thread` instance *`t`* models a thread. You can pass a function to be used as *`t`*'s main function as the *`target`* argument when you create *`t`*, or you can subclass `Thread` and override its `run` method (you may also override `__init__`, but you should not override other methods). *`t`* is not yet ready to run when you create it; to make *`t`* ready (active), call *`t`*`.start`. Once *`t`* is active, it terminates when its main function ends, either normally or by propagating an exception. A `Thread` *`t`* can be a *daemon*, meaning that Python can terminate even if *`t`* is still active, while a normal (nondaemon) thread keeps Python alive until the thread terminates. The `Thread` class supplies the constructor, properties, and methods detailed in Table 15-2.

Table 15-2. Constructor, methods, and properties of the `Thread` class

`Thread`	**`class`** `Thread(name=`**`None`**`, target=`**`None`**`, args=(), kwargs={}, *, daemon=`**`None`**`)` *Always call `Thread` with named arguments*: the number and order of parameters is not guaranteed by the specification, but the parameter names are. You have two options when constructing a `Thread`: • Instantiate the class `Thread` itself with a `target` function (*`t`*`.run` then calls *`target`*`(*`*`args`*`, **`*`kwargs`*`)` when the thread is started). • Extend the `Thread` class and override its `run` method. In either case, execution will begin only when you call *`t`*`.start`. `name` becomes *`t`*'s name. If `name` is **`None`**, `Thread` generates a unique name for *`t`*. If a subclass *`T`* of `Thread` overrides `__init__`, *`T`*`.__init__` *must* call `Thread.__init__` on `self` (usually via the `super` built-in function) before any other `Thread` method. `daemon` can be assigned a Boolean value or, if **`None`**, will take this value from the `daemon` attribute of the creating thread.

`daemon`	`daemon` is a writable Boolean property that indicates whether *t* is a daemon (i.e., the process can terminate even when *t* is still active; such a termination also ends *t*). You can assign to *t*`.daemon` only before calling *t*`.start`; assigning a true value sets *t* to be a daemon. Threads created by a daemon thread have *t*`.daemon` set to **`True`** by default.
`is_alive`	*t*`.is_alive()` `is_alive` returns **`True`** when *t* is active (i.e., when *t*`.start` has executed and *t*`.run` has not yet terminated); otherwise, returns **`False`**.
`join`	*t*`.join(timeout=`**`None`**`)` `join` suspends the calling thread (which must not be *t*) until *t* terminates (when *t* is already terminated, the calling thread does not suspend). `timeout` is covered in "Timeout parameters" on page 448. You can call *t*`.join` only after *t*`.start`. It's OK to call `join` more than once.
`name`	*t*`.name` `name` is a property returning *t*'s name; assigning `name` rebinds *t*'s name (`name` exists only to help you debug; `name` need not be unique among threads). If omitted, the thread will receive a generated name `Thread-`*n*, where *n* is an incrementing integer (**3.10+** and if `target` is specified, `(target.__name__)` will be appended).
`run`	*t*`.run()` `run` is the method called by *t*`.start` that executes *t*'s main function. Subclasses of `Thread` can override `run`. Unless overridden, `run` calls the *`target`* callable passed on *t*'s creation. Do *not* call *t*`.run` directly; calling *t*`.run` is the job of *t*`.start`!
`start`	*t*`.start()` `start` makes *t* active and arranges for *t*`.run` to execute in a separate thread. You must call *t*`.start` only once for any given `Thread` object *t*; calling it again raises an exception.

Thread Synchronization Objects

The `threading` module supplies several synchronization primitives (types that let threads communicate and coordinate). Each primitive type has specialized uses, discussed in the following sections.

You May Not Need Thread Synchronization Primitives

As long as you avoid having (nonqueue) global variables that change and which several threads access, `queue` (covered in "The queue Module" on page 456) can often provide all the coordination you need, as can `concurrent` (covered in "The concurrent.futures Module" on page 468). "Threaded Program Architecture" on page 471 shows how to use `Queue` objects to give your multithreaded programs simple and effective architectures, often without needing any explicit use of synchronization primitives.

Timeout parameters

The synchronization primitives `Condition` and `Event` supply `wait` methods that accept an optional `timeout` argument. A `Thread` object's `join` method also accepts an optional timeout argument (see Table 15-2). Using the default timeout value of **None** results in normal blocking behavior (the calling thread suspends and waits until the desired condition is met). When it is not **None**, a timeout argument is a floating-point value that indicates an interval of time, in seconds (timeout can have a fractional part, so it can indicate any time interval, even a very short one). When timeout seconds elapse, the calling thread becomes ready again, even if the desired condition has not been met; in this case, the waiting method returns **False** (otherwise, the method returns **True**). timeout lets you design systems that are able to overcome occasional anomalies in a few threads, and thus are more robust. However, using timeout may slow your program down: when that matters, be sure to measure your code's speed accurately.

Lock and RLock objects

Lock and RLock objects supply the same three methods, described in Table 15-3.

Table 15-3. Methods of an instance L of Lock

acquire	*L*.acquire(blocking=**True**, timeout=-1) When *L* is unlocked, or if *L* is an RLock acquired by the same thread that's calling acquire, this thread immediately locks it (incrementing the internal counter if *L* is an RLock, as described shortly) and returns **True**. When *L* is already locked and blocking is **False**, acquire immediately returns **False**. When blocking is **True**, the calling thread is suspended until either: • Another thread releases the lock, in which case this thread locks it and returns **True**. • The operation times out before the lock can be acquired, in which case acquire returns **False**. The default -1 value never times out.
locked	*L*.locked() Returns **True** when *L* is locked; otherwise, returns **False**.
release	*L*.release() Unlocks *L*, which must be locked (for an RLock, this means to decrement the lock count, which cannot go below zero—the lock can only be acquired by a new thread when the lock count is zero). When *L* is locked, any thread may call *L*.release, not just the thread that locked *L*. When more than one thread is blocked on *L* (i.e., has called *L*.acquire, found *L* locked, and is waiting for *L* to be unlocked), release wakes up an arbitrary one of the waiting threads. The thread calling release does not suspend: it remains ready and continues to execute.

The following console session illustrates the automatic acquire/release done on locks when they are used as a context manager (as well as other data Python maintains for the lock, such as the owner thread ID and the number of times the lock's acquire method has been called):

```
>>> lock = threading.RLock()
>>> print(lock)

<unlocked _thread.RLock object owner=0 count=0 at 0x102878e00>
```

```
>>> with lock:
...     print(lock)
...
<locked _thread.RLock object owner=4335175040 count=1 at 0x102878e00>
>>> print(lock)
<unlocked _thread.RLock object owner=0 count=0 at 0x102878e00>
```

The semantics of an `RLock` object *`r`* are often more convenient (except in peculiar architectures where you need threads to be able to release locks that a different thread has acquired). `RLock` is a *reentrant* lock, meaning that when *`r`* is locked, it keeps track of the *owning* thread (i.e., the thread that locked it, which for an `RLock` is also the only thread that can release it—when any other thread tries to release an `RLock`, this raises a `RuntimeError` exception). The owning thread can call *`r`*`.acquire` again without blocking; *`r`* then just increments an internal count. In a similar situation involving a `Lock` object, the thread would block until some other thread releases the lock. For example, consider the following code snippet:

```
lock = threading.RLock()
global_state = []
def recursive_function(some, args):
    with lock:  # acquires lock, guarantees release at end
        # ...modify global_state...
        if more_changes_needed(global_state):
            recursive_function(other, args)
```

If `lock` was an instance of `threading.Lock`, `recursive_function` would block its calling thread when it calls itself recursively: the **`with`** statement, finding that the lock has already been acquired (even though that was done by the same thread), would block and wait…and wait. With a `threading.RLock`, no such problem occurs: in this case, since the lock has already been acquired *by the same thread*, on getting acquired again it just increments its internal count and proceeds.

An `RLock` object *`r`* is unlocked only when it has been released as many times as it has been acquired. An `RLock` is useful to ensure exclusive access to an object when the object's methods call each other; each method can acquire at the start, and release at the end, the same `RLock` instance.

Use with Statements to Automatically Acquire and Release Synchronization Objects

Using a **`try`**/**`finally`** statement (covered in "try/finally" on page 198) is one way to ensure that an acquired lock is indeed released. Using a **`with`** statement, covered in "The with Statement and Context Managers" on page 201, is usually better: all locks, conditions, and semaphores are context managers, so an instance of any of these types can be used directly in a **`with`** clause to acquire it (implicitly with blocking) and ensure it is released at the end of the **`with`** block.

Condition objects

A Condition object *c* wraps a Lock or RLock object *L*. The class Condition exposes the constructor and methods described in Table 15-4.

Table 15-4. Constructor and methods of the Condition class

Condition	**class** Condition(lock=**None**) Creates and returns a new Condition object *c* with the lock *L* set to lock. If lock is **None**, *L* is set to a newly created RLock object.
acquire, release	*c*.acquire(blocking=**True**), *c*.release() These methods just call *L*'s corresponding methods. A thread must never call any other method on *c* unless the thread holds (i.e., has acquired) lock *L*.
notify, notify_all	*c*.notify(), *c*.notify_all() notify wakes up an arbitrary one of the threads waiting on *c*. The calling thread must hold *L* before it calls *c*.notify, and notify does not release *L*. The awakened thread does not become ready until it can acquire *L* again. Therefore, the calling thread normally calls release after calling notify. notify_all is like notify, but wakes up *all* waiting threads, not just one.
wait	*c*.wait(timeout=**None**) wait releases *L*, then suspends the calling thread until some other thread calls notify or notify_all on *c*. The calling thread must hold *L* before it calls *c*.wait. timeout is covered in "Timeout parameters" on page 448. After a thread wakes up, either by notification or timeout, the thread becomes ready when it acquires *L* again. When wait returns **True** (meaning it has exited normally, not by timeout), the calling thread is always holding *L* again.

Usually, a Condition object *c* regulates access to some global state *s* shared among threads. When a thread must wait for *s* to change, the thread loops:

```
with c:
    while not is_ok_state(s):
        c.wait()
    do_some_work_using_state(s)
```

Meanwhile, each thread that modifies *s* calls notify (or notify_all if it needs to wake up all waiting threads, not just one) each time *s* changes:

```
with c:
    do_something_that_modifies_state(s)
    c.notify()    # or, c.notify_all()
# no need to call c.release(), exiting 'with' intrinsically does that
```

You must always acquire and release *c* around each use of *c*'s methods: doing so via a **with** statement makes using Condition instances less error prone.

Event objects

Event objects let any number of threads suspend and wait. All threads waiting on Event object *e* become ready when any other thread calls *e*.set. *e* has a flag that records whether the event happened; it is initially **False** when *e* is created. Event is thus a bit like a simplified Condition. Event objects are useful to signal one-shot changes, but brittle for more general use; in particular, relying on calls to *e*.clear is error prone. The Event class exposes the constructor and methods in Table 15-5.

Table 15-5. Constructor and methods of the Event class

Event	**class** Event() Creates and returns a new Event object *e*, with *e*'s flag set to **False**.
clear	*e*.clear() Sets *e*'s flag to **False**.
is_set	*e*.is_set() Returns the value of *e*'s flag: **True** or **False**.
set	*e*.set() Sets *e*'s flag to **True**. All threads waiting on *e*, if any, become ready to run.
wait	*e*.wait(timeout=**None**) Returns immediately if *e*'s flag is **True**; otherwise, suspends the calling thread until some other thread calls set. timeout is covered in "Timeout parameters" on page 448.

The following code shows how Event objects explicitly synchronize processing across multiple threads:

```
import datetime, random, threading, time

def runner():
    print('starting')
    time.sleep(random.randint(1, 3))
    print('waiting')
    event.wait()
    print(f'running at {datetime.datetime.now()}')

num_threads = 10
event = threading.Event()

threads = [threading.Thread(target=runner) for _ in range(num_threads)]
for t in threads:
    t.start()

event.set()

for t in threads:
    t.join()
```

Semaphore and BoundedSemaphore objects

Semaphores (also known as *counting semaphores*) are a generalization of locks. The state of a `Lock` can be seen as **`True`** or **`False`**; the state of a `Semaphore` *`s`* is a number between `0` and some *`n`* set when *`s`* is created (both bounds included). `Semaphore`s can be useful to manage a fixed pool of resources—e.g., 4 printers or 20 sockets—although it's often more robust to use `Queue`s (described later in this chapter) for such purposes. The class `BoundedSemaphore` is very similar, but raises `ValueError` if the state ever becomes higher than the initial value: in many cases, such behavior can be a useful indicator of a bug. Table 15-6 shows the constructors of the `Semaphore` and `BoundedSemaphore` classes and the methods exposed by an object *s* of either class.

Table 15-6. Constructors and methods of the `Semaphore` and `BoundedSemaphore` classes

`Semaphore`, `Bounded Semaphore`	**`class`** `Semaphore(n=1)`, **`class`** `BoundedSemaphore(n=1)` `Semaphore` creates and returns a `Semaphore` object *`s`* with the state set to `n`; `Bounded Semaphore` is very similar, except that *`s`*`.release` raises `ValueError` if the state becomes higher than `n`.
`acquire`	*`s`*`.acquire(blocking=`**`True`**`)` When *`s`*'s state is >`0`, `acquire` decrements the state by `1` and returns **`True`**. When *`s`*'s state is `0` and `blocking` is **`True`**, `acquire` suspends the calling thread and waits until some other thread calls *`s`*`.release`. When *`s`*'s state is `0` and `blocking` is **`False`**, `acquire` immediately returns **`False`**.
`release`	*`s`*`.release()` When *`s`*'s state is >`0`, or when the state is `0` but no thread is waiting on *`s`*, `release` increments the state by `1`. When *`s`*'s state is `0` and some threads are waiting on *`s`*, `release` leaves *`s`*'s state at `0` and wakes up an arbitrary one of the waiting threads. The thread that calls `release` does not suspend; it remains ready and continues to execute normally.

Timer objects

A `Timer` object calls a specified callable, in a newly made thread, after a given delay. The class `Timer` exposes the constructor and methods in Table 15-7.

Table 15-7. Constructor and methods of the `Timer` class

`Timer`	**`class`** `Timer(`*`interval`*`, `*`callback`*`, args=`**`None`**`, kwargs=`**`None`**`)` Creates an object *`t`* that calls *`callback`*, *`interval`* seconds after starting (*`interval`* is a floating-point number of seconds).
`cancel`	*`t`*`.cancel()` Stops the timer and cancels the execution of its action, as long as *`t`* is still waiting (hasn't called its callback yet) when you call `cancel`.

`start`	`t.start()` Starts *t*.

`Timer` extends `Thread` and adds the attributes `function`, `interval`, `args`, and `kwargs`.

A `Timer` is "one-shot": *`t`* calls its callback only once. To call *`callback`* periodically, every *`interval`* seconds, here's a simple recipe—the `Periodic` timer runs *`callback`* every *`interval`* seconds, stopping only when *`callback`* raises an exception:

```
class Periodic(threading.Timer):
    def __init__(self, interval, callback, args=None, kwargs=None):
        super().__init__(interval, self._f, args, kwargs)
        self.callback = callback

    def _f(self, *args, **kwargs):
        p = type(self)(self.interval, self.callback, args, kwargs)
        p.start()
        try:
            self.callback(*args, **kwargs)
        except Exception:
            p.cancel()
```

Barrier objects

A `Barrier` is a synchronization primitive allowing a certain number of threads to wait until they've all reached a certain point in their execution, at which point they all resume. Specifically, when a thread calls *`b`*`.wait`, it blocks until the specified number of threads have made the same call on *b*; at that time, all the threads blocked on *b* are allowed to resume.

The `Barrier` class exposes the constructor, methods, and properties listed in Table 15-8.

Table 15-8. Constructor, methods, and properties of the `Barrier` class

`Barrier`	**`class`** `Barrier(`*`num_threads`*`, action=`**`None`**`, timeout=`**`None`**`)` Creates a `Barrier` object *b* for *`num_threads`* threads. `action` is a callable without arguments: if you pass this argument, it executes on any single one of the blocked threads when they are all unblocked. `timeout` is covered in "Timeout parameters" on page 448.
`abort`	*`b`*`.abort()` Puts `Barrier` *b* in the *broken* state, meaning that any thread currently waiting resumes with a `threading.BrokenBarrierException` (the same exception also gets raised on any subsequent call to *`b`*`.wait`). This is an emergency action typically used when a waiting thread is suffering some abnormal termination, to avoid deadlocking the whole program.
`broken`	*`b`*`.broken` **`True`** when *b* is in the broken state; otherwise, **`False`**.

`n_waiting`	*b*.`n_waiting` The number of threads currently waiting on *b*.
`parties`	`parties` The value passed as *`num_threads`* in the constructor of *b*.
`reset`	*b*.`reset()` Returns *b* to the initial empty, nonbroken state; any thread currently waiting on *b*, however, resumes with a `threading.BrokenBarrierException`.
`wait`	*b*.`wait()` The first *b*.`parties-1` threads calling *b*.`wait` block; when the number of threads blocked on *b* is *b*.`parties-1` and one more thread calls *b*.`wait`, all the threads blocked on *b* resume. *b*.`wait` returns an `int` to each resuming thread, all distinct and in `range(`*b*`.parties)`, in unspecified order; threads can use this return value to determine which one should do what next (though passing `action` in the `Barrier`'s constructor is simpler and often sufficient).

The following code shows how `Barrier` objects synchronize processing across multiple threads (contrast this with the example code shown earlier for `Event` objects):

```
import datetime, random, threading, time

def runner():
    print('starting')
    time.sleep(random.randint(1, 3))
    print('waiting')
    try:
        my_number = barrier.wait()
    except threading.BrokenBarrierError:
        print('Barrier abort() or reset() called, thread exiting...')
        return
    print(f'running ({my_number}) at {datetime.datetime.now()}')

def announce_release():
    print('releasing')

num_threads = 10
barrier = threading.Barrier(num_threads, action=announce_release)

threads = [threading.Thread(target=runner) for _ in range(num_threads)]
for t in threads:
    t.start()

for t in threads:
    t.join()
```

Thread Local Storage

The `threading` module supplies the class `local`, which a thread can use to obtain *thread-local storage*, also known as *per-thread data*. An instance *L* of `local` has arbitrary named attributes that you can set and get, stored in a dictionary

L.__dict__ that you can also access. *L* is fully thread-safe, meaning there is no problem if multiple threads simultaneously set and get attributes on *L*. Each thread that accesses *L* sees a disjoint set of attributes: any changes made in one thread have no effect in other threads. For example:

```
import threading

L = threading.local()
print('in main thread, setting zop to 42')
L.zop = 42

def targ():
  print('in subthread, setting zop to 23')
  L.zop = 23
  print('in subthread, zop is now', L.zop)

t = threading.Thread(target=targ)
t.start()
t.join()
print('in main thread, zop is now', L.zop)
# prints:
# in main thread, setting zop to 42
# in subthread, setting zop to 23
# in subthread, zop is now 23
# in main thread, zop is now 42
```

Thread-local storage makes it easier to write code meant to run in multiple threads, since you can use the same namespace (an instance of `threading.local`) in multiple threads without the separate threads interfering with each other.

The queue Module

The `queue` module supplies queue types supporting multithreaded access, with one main class `Queue`, one simplified class `SimpleQueue`, two subclasses of the main class (`LifoQueue` and `PriorityQueue`), and two exception classes (`Empty` and `Full`), described in Table 15-9. The methods exposed by instances of the main class and its subclasses are detailed in Table 15-10.

Table 15-9. Classes of the `queue` module

`Queue`	**`class`** `Queue(maxsize=0)` `Queue`, the main class in the module `queue`, implements a first-in, first-out (FIFO) queue: the item retrieved each time is the one that was added earliest. When `maxsize > 0`, the new `Queue` instance *q* is considered full when *q* has `maxsize` items. When *q* is full, a thread inserting an item with `block=True` suspends until another thread extracts an item. When `maxsize <= 0`, *q* is never considered full and is limited in size only by available memory, like most Python containers.

`SimpleQueue`	**`class`** `SimpleQueue` `SimpleQueue` is a simplified `Queue`: an unbounded FIFO queue lacking the methods `full`, `task_done`, and `join` (see Table 15-10) and with the method `put` ignoring its optional arguments but guaranteeing reentrancy (which makes it usable in `__del__` methods and `weakref` callbacks, where `Queue.put` would not be).
`LifoQueue`	**`class`** `LifoQueue(maxsize=0)` `LifoQueue` is a subclass of `Queue`; the only difference is that `LifoQueue` implements a last-in, first-out (LIFO) queue, meaning the item retrieved each time is the most recently added one (often called a *stack*).
`PriorityQueue`	**`class`** `PriorityQueue(maxsize=0)` `PriorityQueue` is a subclass of `Queue`; the only difference is that `PriorityQueue` implements a *priority* queue, meaning the item retrieved each time is the smallest one currently in the queue. Since there is no way to specify ordering, you'll typically use `(`*`priority, payload`*`)` pairs as items, with low values of *`priority`* meaning earlier retrieval.
`Empty`	`Empty` is the exception that *`q`*`.get(block=`**`False`**`)` raises when *q* is empty.
`Full`	`Full` is the exception that *`q`*`.put(`*`x`*`, block=`**`False`**`)` raises when *q* is full.

An instance *q* of the class `Queue` (or either of its subclasses) supplies the methods listed in Table 15-10, all thread-safe and guaranteed to be atomic. For details on the methods exposed by an instance of `SimpleQueue`, see Table 15-9.

Table 15-10. Methods of an instance q of class `Queue`, `LifoQueue`, or `PriorityQueue`

`empty`	*`q`*`.empty()` Returns **`True`** when *q* is empty; otherwise, returns **`False`**.
`full`	*`q`*`.full()` Returns **`True`** when *q* is full; otherwise, returns **`False`**.
`get`, `get_nowait`	*`q`*`.get(block=`**`True`**`, timeout=`**`None`**`)`, *`q`*`.get_nowait()` When `block` is **`False`**, `get` removes and returns an item from *q* if one is available; otherwise, `get` raises `Empty`. When `block` is **`True`** and `timeout` is **`None`**, `get` removes and returns an item from *q*, suspending the calling thread, if need be, until an item is available. When `block` is **`True`** and `timeout` is not **`None`**, `timeout` must be a number `>=0` (which may include a fractional part to specify a fraction of a second), and `get` waits for no longer than `timeout` seconds (if no item is yet available by then, `get` raises `Empty`). *`q`*`.get_nowait()` is like *`q`*`.get(`**`False`**`)`, which is also like *`q`*`.get(timeout=0.0)`. `get` removes and returns items: in the same order as `put` inserted them (FIFO) if *q* is a direct instance of `Queue` itself, in LIFO order if *q* is an instance of `LifoQueue`, or in smallest-first order if *q* is an instance of `PriorityQueue`.

Threads and Processes

put,
put_nowait
	`q.put(item, block=True, timeout=None)`
	`q.put_nowait(item)`
	When `block` is **`False`**, `put` adds *`item`* to *q* if *q* is not full; otherwise, `put` raises `Full`. When `block` is **`True`** and `timeout` is **`None`**, `put` adds *`item`* to *q*, suspending the calling thread, if need be, until *q* is not full. When `block` is **`True`** and `timeout` is not **`None`**, `timeout` must be a number `>=0` (which may include a fractional part to specify a fraction of a second), and `put` waits for no longer than `timeout` seconds (if *q* is still full by then, `put` raises `Full`). `q.put_nowait(item)` is like `q.put(item, False)`, which is also like `q.put(item, timeout=0.0)`.

qsize	`q.qsize()` Returns the number of items that are currently in *q*.

q maintains an internal, hidden count of *unfinished tasks*, which starts at zero. Each call to `put` increments the count by one. To decrement the count by one, when a worker thread has finished processing a task, it calls `q.task_done`. To synchronize on "all tasks done," call `q.join`: when the count of unfinished tasks is nonzero, `q.join` blocks the calling thread, unblocking later when the count goes to zero; when the count of unfinished tasks is zero, `q.join` continues the calling thread.

You don't have to use `join` and `task_done` if you prefer to coordinate threads in other ways, but they provide a simple, useful approach when you need to coordinate systems of threads using a `Queue`.

`Queue` offers a good example of the idiom "It's easier to ask forgiveness than permission" (EAFP), covered in "Error-Checking Strategies" on page 214. Due to multithreading, each nonmutating method of *q* (`empty`, `full`, `qsize`) can only be advisory. When some other thread mutates *q*, things can change between the instant a thread gets information from a nonmutating method and the very next moment, when the thread acts on the information. Relying on the "look before you leap" (LBYL) idiom is therefore futile, and fiddling with locks to try to fix things is a substantial waste of effort. Avoid fragile LBYL code, such as:

```
if q.empty():
    print('no work to perform')
else:  # Some other thread may now have emptied the queue!
    x = q.get_nowait()
    work_on(x)
```

and instead use the simpler and more robust EAFP approach:

```
try:
    x = q.get_nowait()
except queue.Empty:  # Guarantees the queue was empty when accessed
    print('no work to perform')
else:
    work_on(x)
```

The multiprocessing Module

The `multiprocessing` module supplies functions and classes to code pretty much as you would for multithreading, but distributing work across processes, rather than across threads: these include the class `Process` (analogous to `threading.Thread`) and classes for synchronization primitives (`Lock`, `RLock`, `Condition`, `Event`, `Semaphore`, `BoundedSemaphore`, and `Barrier`—each similar to the class with the same name in the `threading` module—as well as `Queue` and `JoinableQueue`, both similar to `queue.Queue`). These classes make it easy to take code written to use `threading` and port it to a version using `multiprocessing` instead; just pay attention to the differences we cover in the following subsection.

It's usually best to avoid sharing state among processes: use queues, instead, to explicitly pass messages among them. However, for those rare occasions in which you do need to share some state, `multiprocessing` supplies classes to access shared memory (`Value` and `Array`), and—more flexibly (including coordination among different computers on a network) though with more overhead—a `Process` subclass, `Manager`, designed to hold arbitrary data and let other processes manipulate that data via *proxy* objects. We cover state sharing in "Sharing State: Classes Value, Array, and Manager" on page 461.

When you're writing new code, rather than porting code originally written to use `threading`, you can often use different approaches supplied by `multiprocessing`. The `Pool` class, in particular (covered in "Process Pools" on page 464), can often simplify your code. The simplest and highest-level way to do multiprocessing is to use the `concurrent.futures` module (covered in "The concurrent.futures Module" on page 468) along with the `ProcessPoolExecutor`.

Other highly advanced approaches, based on `Connection` objects built by the `Pipe` factory function or wrapped in `Client` and `Listener` objects, are even more flexible, but quite a bit more complex; we do not cover them further in this book. For more in-depth coverage of `multiprocessing`, refer to the online docs[2] and third-party online tutorials like in PyMOTW.

2 The online docs include an especially helpful "Programming Guidelines" section that lists a number of additional practical recommendations when using the `multiprocessing` module.

Differences Between multiprocessing and threading

You can pretty easily port code written to use `threading` into a variant using `multiprocessing` instead—however, there are several differences you must consider.

Structural differences

All objects that you exchange between processes (for example, via a queue, or an argument to a `Process`'s `target` function) are serialized via `pickle`, covered in "The pickle Module" on page 389. Therefore, you can only exchange objects that can be thus serialized. Moreover, the serialized bytestring cannot exceed about 32 MB (depending on the platform), or else an exception is raised; therefore, there are limits to the size of objects you can exchange.

Especially in Windows, child processes *must* be able to import as a module the main script that's spawning them. Therefore, be sure to guard all top-level code in the main script (meaning code that must not be executed again by child processes) with the usual `if __name__ == '__main__'` idiom, covered in "The Main Program" on page 230.

If a process is abruptly killed (for example, via a signal) while using a queue or holding a synchronization primitive, it won't be able to perform proper cleanup on that queue or primitive. As a result, the queue or primitive may get corrupted, causing errors in all other processes trying to use it.

The Process class

The class `multiprocessing.Process` is very similar to `threading.Thread`; it supplies all the same attributes and methods (see Table 15-2), plus a few more, listed in Table 15-11. Its constructor has the following signature:

`Process`	`class Process(name=None, target=None, args=(), kwargs={})` *Always call `Process` with named arguments*: the number and order of parameters is not guaranteed by the specification, but the parameter names are. Either instantiate the class `Process` itself, passing a `target` function (`p.run` then calls `target(*args, **kwargs)` when the thread is started); or, instead of passing `target`, extend the `Process` class and override its `run` method. In either case, execution will begin only when you call `p.start`. `name` becomes *p*'s name. If `name` is **None**, `Process` generates a unique name for *p*. If a subclass *P* of `Process` overrides `__init__`, *P*.`__init__` *must* call `Process.__init__` on `self` (usually via the `super` built-in function) before any other `Process` method.

Table 15-11. Additional attributes and methods of the `Process` class

`authkey`	The process's authorization key, a bytestring. This is initialized to random bytes supplied by `os.urandom`, but you can reassign it later if you wish. Used in the authorization handshake for advanced uses we do not cover in this book.

`close`	`close()` Closes a `Process` instance and releases all resources associated with it. If the underlying process is still running, raises `ValueError`.
`exitcode`	**None** when the process has not exited yet; otherwise, the process's exit code. This is an `int`: `0` for success, `>0` for failure, `<0` when the process was killed.
`kill`	`kill()` Same as `terminate`, but on Unix sends a `SIGKILL` signal.
`pid`	**None** when the process has not started yet; otherwise, the process's identifier as set by the operating system.
`terminate`	`terminate()` Kills the process (without giving it a chance to execute termination code, such as cleanup of queues and synchronization primitives; beware of the likelihood of causing errors when the process is using a queue or holding a synchronization primitive!).

Differences in queues

The class `multiprocessing.Queue` is very similar to `queue.Queue`, except that an instance *`q`* of `multiprocessing.Queue` does *not* supply the methods `join` and `task_done` (described in "The queue Module" on page 456). When methods of *`q`* raise exceptions due to timeouts, they raise instances of `queue.Empty` or `queue.Full`. `multiprocessing` has no equivalents to `queue`'s `LifoQueue` and `PriorityQueue` classes.

The class `multiprocessing.JoinableQueue` does supply the methods `join` and `task_done`, but with a semantic difference compared to `queue.Queue`: with an instance *`q`* of `multiprocessing.JoinableQueue`, the process that calls *`q`*`.get` *must* call *`q`*`.task_done` when it's done processing that unit of work (it's not optional, as it is when using `queue.Queue`).

All objects you `put` in multiprocessing queues must be serializable by `pickle`. There may be a delay between the time you execute `q.put` and the time the object is available from `q.get`. Lastly, remember that an abrupt exit (crash or signal) of a process using *`q`* may leave *`q`* unusable for any other process.

Sharing State: Classes Value, Array, and Manager

To use shared memory to hold a single primitive value in common among two or more processes, `multiprocessing` supplies the class `Value`, and for a fixed-length array of primitive values, it provides the class `Array`. For more flexibility (including sharing nonprimitive values and "sharing" among different systems joined by a network but sharing no memory), at the cost of higher overhead, `multiprocessing` supplies the class `Manager`, which is a subclass of `Process`. We'll look at each of these in the following subsections.

The Value class

The constructor for the class `Value` has the signature:

Value **`class Value(`*`typecode`*`, *`*`args`*`, *, lock=True)`**

`typecode` is a string defining the primitive type of the value, just like for the `array` module, covered in "The array Module" on page 502. (Alternatively, *`typecode`* can be a type from the module `ctypes`, discussed in "ctypes" in Chapter 25, but this is rarely necessary.) *`args`* is passed on to the type's constructor: therefore, *`args`* is either absent (in which case the primitive is initialized as per its default, typically `0`) or a single value, which is used to initialize the primitive.

When `lock` is **`True`** (the default), `Value` makes and uses a new lock to guard the instance. Alternatively, you can pass as `lock` an existing `Lock` or `RLock` instance. You can even pass `lock=`**`False`**, but that is rarely advisable: when you do, the instance is not guarded (thus, it is not synchronized among processes) and is missing the method `get_lock`. If you do pass `lock`, you *must* pass it as a named argument, using `lock=`*`something`*.

An instance *`v`* of the class `Value` supplies the method `get_lock`, which returns (but neither acquires nor releases) the lock guarding *v*, and the read/write attribute `value`, used to set and get *v*'s underlying primitive value.

To ensure atomicity of operations on *v*'s underlying primitive value, guard the operation in a **`with`** *`v`*`.get_lock():` statement. A typical example of such usage might be for augmented assignment, as in:

```
with v.get_lock():
    v.value += 1
```

If any other process does an unguarded operation on that same primitive value, however—even an atomic one such as a simple assignment like *`v`*`.value = `*`x`*—all bets are off: the guarded operation and the unguarded one can get your system into a *race condition*.[3] Play it safe: if *any* operation at all on *`v`*`.value` is not atomic (and thus needs to be guarded by being within a **`with`** *`v`*`.get_lock():` block), guard *all* operations on *`v`*`.value` by placing them within such blocks.

The Array class

A `multiprocessing.Array` is a fixed-length array of primitive values, with all items of the same primitive type. The constructor for the class `Array` has the signature:

3 A race condition is a situation in which the relative timings of different events, which are usually unpredictable, can affect the outcome of a computation…never a good thing!

`Array` **class** `Array(`*`typecode`*`, `*`size_or_initializer`*`, *, lock=`**`True`**`)`

`typecode` is a string defining the primitive type of the value, just like for the module `array`, as covered in "The array Module" on page 502. (Alternatively, *`typecode`* can be a type from the module `ctypes`, discussed in "ctypes" in Chapter 25, but this is rarely necessary.) *`size_or_initializer`* can be an iterable, used to initialize the array, or an integer used as the length of the array, in which case each item of the array is initialized to `0`.

When `lock` is **`True`** (the default), `Array` makes and uses a new lock to guard the instance. Alternatively, you can pass as `lock` an existing `Lock` or `RLock` instance. You can even pass `lock=`**`False`**, but that is rarely advisable: when you do, the instance is not guarded (thus it is not synchronized among processes) and is missing the method `get_lock`. If you do pass `lock`, you *must* pass it as a named argument, using `lock=`*`something`*.

An instance *a* of the class `Array` supplies the method `get_lock`, which returns (but neither acquires nor releases) the lock guarding *a*.

a is accessed by indexing and slicing, and modified by assigning to an indexing or to a slice. *a* is fixed length: therefore, when you assign to a slice, you must assign an iterable of exactly the same length as the slice you're assigning to. *a* is also iterable.

In the special case where *a* was built with a *`typecode`* of `'c'`, you can also access *a*`.value` to get *a*'s contents as a bytestring, and you can assign to *a*`.value` any bytestring no longer than `len(`*`a`*`)`. When *s* is a bytestring with `len(`*`s`*`) < len(`*`a`*`)`, *a*`.value = `*`s`* means *a*`[:len(`*`s`*`)+1] = `*`s`*` + b'\0'`; this mirrors the representation of `char` strings in the C language, terminated with a `0` byte. For example:

```
a = multiprocessing.Array('c', b'four score and seven')
a.value = b'five'
print(a.value)   # prints b'five'
print(a[:])      # prints b'five\x00score and seven'
```

The Manager class

`multiprocessing.Manager` is a subclass of `multiprocessing.Process`, with the same methods and attributes. In addition, it supplies methods to build an instance of any of the multiprocessing synchronization primitives, plus `Queue`, `dict`, `list`, and `Namespace`, the latter being a class that just lets you set and get arbitrary named attributes. Each of the methods has the name of the class whose instances it builds, and returns a *proxy* to such an instance, which any process can use to call methods (including special methods, such as indexing of instances of `dict` or `list`) on the instance held in the manager process.

Proxy objects pass most operators, and accesses to methods and attributes, on to the instance they proxy for; however, they don't pass on *comparison* operators—if you need a comparison, you need to take a local copy of the proxied object. For example:

```
manager = multiprocessing.Manager()
p = manager.list()

p[:] = [1, 2, 3]
```

```
    print(p == [1, 2, 3])       # prints False,  it compares with p itself
    print(list(p) == [1, 2, 3]) # prints True,  it compares with copy
```

The constructor of `Manager` takes no arguments. There are advanced ways to customize `Manager` subclasses to allow connections from unrelated processes (including ones on different computers connected via a network) and to supply a different set of building methods, but we do not cover them in this book. Rather, one simple, often-sufficient approach to using `Manager` is to explicitly transfer to other processes the proxies it produces, typically via queues, or as arguments to a `Process`'s *`target`* function.

For example, suppose there is a long-running, CPU-bound function *f* that, given a string as an argument, eventually returns a corresponding result; given a `set` of strings, we want to produce a `dict` with the strings as keys and the corresponding results as values. To be able to follow on which processes *f* runs, we also `print` the process ID just before calling *f*. Example 15-1 shows one way to do this.

Example 15-1. Distributing work to multiple worker processes

```
import multiprocessing as mp
def f(s):
    """Run a long time, and eventually return a result."""
    import time, random
    time.sleep(random.random()*2)  # simulate slowness
    return s+s                     # some computation or other

def runner(s, d):
    print(os.getpid(), s)
    d[s] = f(s)

def make_dict(strings):
    mgr = mp.Manager()
    d = mgr.dict()
    workers = []
    for s in strings:
        p = mp.Process(target=runner, args=(s, d))
        p.start()
        workers.append(p)
    for p in workers:
        p.join()
    return {**d}
```

Process Pools

In real life, you should always avoid creating an unbounded number of worker processes, as we did in Example 15-1. Performance benefits accrue only up to the number of cores in your machine (available by calling `multiprocessing.cpu_count`), or a number just below or just above this, depending on such minutiae as your platform, how CPU-bound or I/O-bound your code is, other tasks running on your computer, etc. Making many more worker processes than such an optimal number incurs substantial extra overhead without any compensating benefit.

As a consequence, it's a common design pattern to start a *pool* with a limited number of worker processes, and farm out work to them. The class `multiprocessing.Pool` lets you orchestrate this pattern.

The Pool class

The constructor for the class `Pool` has the signature:

`Pool`	**class** `Pool(processes=None, initializer=`**None**`, initargs=(), maxtasksperchild=`**None**`)` `processes` is the number of processes in the pool; it defaults to the value returned by `cpu_count`. When `initializer` is not **None**, it's a function, called at the start of each process in the pool, with `initargs` as arguments, like `initializer(*`*`initargs`*`)`. When `maxtasksperchild` is not **None**, it's the maximum number of tasks that can be executed in each process in the pool. When a process in the pool has executed that many tasks, it terminates, then a new process starts and joins the pool. When `maxtasksperchild` is **None** (the default), each process lives as long as the pool.

An instance *p* of the class `Pool` supplies the methods listed in Table 15-12 (each of them must be called only in the process that built instance *p*).

Table 15-12. Methods of an instance p of class `Pool`

`apply`	`apply(`*`func`*`, args=(), kwds={})` In an arbitrary one of the worker processes, runs *`func`*`(*`*`args`*`, **`*`kwds`*`)`, waits for it to finish, and returns *`func`*'s result.
`apply_async`	`apply_async(`*`func`*`, args=(), kwds={}, callback=`**None**`)` In an arbitrary one of the worker processes, starts running *`func`*`(*`*`args`*`, **`*`kwds`*`)` and, without waiting for it to finish, immediately returns an `AsyncResult` instance, which eventually gives *`func`*'s result, when that result is ready. (The `AsyncResult` class is discussed in the following section.) When `callback` is not **None**, it's a function to call (in a new, separate thread in the process that calls `apply_async`), with *`func`*'s result as the only argument, when that result is ready; `callback` should execute rapidly, because otherwise it blocks the calling process. `callback` may mutate its argument if that argument is mutable; `callback`'s return value is irrelevant (so, the best, clearest style is to have it return **None**).
`close`	`close()` Sets a flag prohibiting further submissions to the pool. Worker processes terminate when they're done with all outstanding tasks.

`imap`	`imap(`*`func`*`, `*`iterable`*`, chunksize=1)` Returns an iterator calling *`func`* on each item of *`iterable`*, in order. `chunksize` determines how many consecutive items are sent to each process; on a very long *`iterable`*, a large `chunksize` can improve performance. When `chunksize` is `1` (the default), the returned iterator has a method `next` (even though the canonical name of the iterator's method is `__next__`), accepting an optional *`timeout`* argument (a floating-point value, in seconds) and raising `multiprocessing.TimeoutError` should the result not yet be ready after *`timeout`* seconds.
`imap_unordered`	`imap_unordered(`*`func`*`, `*`iterable`*`, chunksize=1)` Same as `imap`, but the ordering of the results is arbitrary (this can sometimes improve performance when the order of iteration is unimportant). It is usually helpful if the function's return value includes enough information to allow the results to be associated with the values from the iterable used to generate them.
`join`	`join()` Waits for all worker processes to exit. You must call `close` or `terminate` before you call `join`.
`map`	`map(`*`func`*`, `*`iterable`*`, chunksize=1)` Calls *`func`* on each item of *`iterable`*, in order, in worker processes in the pool; waits for them all to finish, and returns the list of results. `chunksize` determines how many consecutive items are sent to each process; on a very long *`iterable`*, a large `chunksize` can improve performance.
`map_async`	`map_async(`*`func`*`, `*`iterable`*`, chunksize=1, callback=`**`None`**`)` Arranges for *`func`* to be called on each item of *`iterable`* in worker processes in the pool; without waiting for any of this to finish, immediately returns an `AsyncResult` instance (described in the following section), which eventually gives the list of *`func`*'s results, when that list is ready. When `callback` is not **None**, it's a function to call (in a separate thread in the process that calls `map_async`) with the list of *`func`*'s results, in order, as the only argument, when that list is ready; `callback` should execute rapidly, since otherwise it blocks the process. `callback` may mutate its list argument; `callback`'s return value is irrelevant (so, best, clearest style is to have it return **None**).
`terminate`	`terminate()` Terminates all worker processes at once, without waiting for them to complete work.

For example, here's a `Pool`-based approach to perform the same task as the code in Example 15-1:

```
import os, multiprocessing as mp
def f(s):
    """Run a long time, and eventually return a result."""
    import time, random
    time.sleep(random.random()*2)  # simulate slowness
    return s+s                     # some computation or other

def runner(s):
    print(os.getpid(), s)
    return s, f(s)
```

```
def make_dict(strings):
    with mp.Pool() as pool:
        d = dict(pool.imap_unordered(runner, strings))
        return d
```

The AsyncResult class

The methods `apply_async` and `map_async` of the class `Pool` return an instance of the class `AsyncResult`. An instance *r* of the class `AsyncResult` supplies the methods listed in Table 15-13.

Table 15-13. Methods of an instance r of class AsyncResult

`get`	`get(timeout=None)` Blocks and returns the result when ready, or re-raises the exception raised while computing the result. When `timeout` is not **None**, it's a floating-point value in seconds; `get` raises `multiprocessing.TimeoutError` should the result not yet be ready after `timeout` seconds.
`ready`	`ready()` Does not block; returns **True** if the call has completed with a result or has raised an exception; otherwise, returns **False**.
`successful`	`successful()` Does not block; returns **True** if the result is ready and the computation did not raise an exception, or returns **False** if the computation raised an exception. If the result is not yet ready, `successful` raises `AssertionError`.
`wait`	`wait(timeout=None)` Blocks and waits until the result is ready. When `timeout` is not **None**, it's a floating-point value in seconds: `wait` raises `multiprocessing.TimeoutError` should the result not yet be ready after `timeout` seconds.

The ThreadPool class

The `multiprocessing.pool` module also offers a class called `ThreadPool`, with exactly the same interface as `Pool`, implemented with multiple threads within a single process (not with multiple processes, despite the module's name). The equivalent `make_dict` code to Example 15-1 using a `ThreadPool` would be:

```
def make_dict(strings):
    num_workers=3
    with mp.pool.ThreadPool(num_workers) as pool:
        d = dict(pool.imap_unordered(runner, strings))
        return d
```

Since a `ThreadPool` uses multiple threads but is limited to running in a single process, it is most suitable for applications where the separate threads are performing overlapping I/O. As stated previously, Python threading offers little advantage when the work is primarily CPU-bound.

In modern Python, you should generally prefer the Executor abstract class from the module concurrent.futures, covered in next section, and its two implementations, ThreadPoolExecutor and ProcessPoolExecutor. In particular, the Future objects returned by submit methods of the executor classes implemented by concurrent.futures are compatible with the asyncio module (which, as previously mentioned, we do not cover in this book, but which is nevertheless a crucial part of much concurrent processing in recent versions of Python). The AsyncResult objects returned by the methods apply_async and map_async of the pool classes implemented by multiprocessing are not asyncio compatible.

The concurrent.futures Module

The concurrent package supplies a single module, futures. concurrent.futures provides two classes, ThreadPoolExecutor (using threads as workers) and ProcessPoolExecutor (using processes as workers), which implement the same abstract interface, Executor. Instantiate either kind of pool by calling the class with one argument, max_workers, specifying how many threads or processes the pool should contain. You can omit max_workers to let the system pick the number of workers.

An instance *e* of the Executor class supports the methods in Table 15-14.

Table 15-14. Methods of an instance e of class Executor

map	map(*func*, **iterables*, timeout=**None**, chunksize=1) Returns an iterator *it* whose items are the results of *func* called with one argument from each of the *iterables*, in order (using multiple worker threads or processes to execute *func* in parallel). When *timeout* is not **None**, it's a float number of seconds: should next(*it*) not produce any result in timeout seconds, raises concurrent.futures.TimeoutError. You may also optionally specify (by name, only) argument chunksize: ignored for a ThreadPoolExecutor; for a ProcessPoolExecutor it sets how many items of each iterable in *iterables* are passed to each worker process.
shutdown	shutdown(wait=**True**) No more calls to map or submit allowed. When wait is **True**, shutdown blocks until all pending futures are done; when **False**, shutdown returns immediately. In either case, the process does not terminate until all pending futures are done.
submit	submit(*func*, **a*, ***k*) Ensures *func*(**a*, ***k*) executes on an arbitrary one of the pool's processes or threads. Does not block, but rather immediately returns a Future instance.

Any instance of an Executor is also a context manager, and therefore suitable for use on a **with** statement (__exit__ being like shutdown(wait=**True**)).

For example, here's a concurrent-based approach to perform the same task as in Example 15-1:

```
import concurrent.futures as cf
def f(s):
    """run a long time and eventually return a result"""
    # ... like before!

def runner(s):
    return s, f(s)

def make_dict(strings):
    with cf.ProcessPoolExecutor() as e:
        d = dict(e.map(runner, strings))
    return d
```

The submit method of an Executor returns a Future instance. A Future instance *f* supplies the methods described in Table 15-15.

Table 15-15. Methods of an instance f of class Future

add_done_callback	add_done_callback(*func*) Adds callable *func* to *f*; *func* gets called, with *f* as the only argument, when *f* completes (i.e., is canceled, or finishes).
cancel	cancel() Tries canceling the call. Returns **False** when the call is being executed and cannot be canceled; otherwise, returns **True**.
cancelled	cancelled() Returns **True** if the call was successfully canceled; otherwise, returns **False**.
done	done() Returns **True** when the call is completed (i.e., finished, or successfully canceled).
exception	exception(timeout=**None**) Returns the exception raised by the call, or **None** if the call raised no exception. When timeout is not **None**, it's a float number of seconds to wait. If the call hasn't completed after timeout seconds, exception raises concurrent.futures.TimeoutError; if the call is canceled, exception raises concurrent.futures.CancelledError.
result	result(timeout=**None**) Returns the call's result. When timeout is not **None**, it's a float number of seconds. If the call hasn't completed within timeout seconds, result raises concurrent.futures.TimeoutError; if the call is canceled, result raises concurrent.futures.CancelledError.
running	running() Returns **True** when the call is executing and cannot be canceled; otherwise, returns **False**.

The `concurrent.futures` module also supplies two functions, detailed in Table 15-16.

Table 15-16. Functions of the `concurrent.futures` module

`as_completed`	`as_completed(`*`fs`*`, timeout=`**`None`**`)` Returns an iterator *`it`* over the `Future` instances that are the items of iterable *`fs`*. If there are duplicates in *`fs`*, each gets yielded just once. *`it`* yields one completed future at a time, in order, as they complete. If `timeout` is not **None**, it's a `float` number of seconds; should it ever happen that no new future can yet be yielded within `timeout` seconds from the previous one, `as_completed` raises `concurrent.futures.Timeout`.

`wait`	`wait(`*`fs`*`, timeout=`**`None`**`, return_when=ALL_COMPLETED)`
	Waits for the `Future` instances that are the items of iterable *`fs`*. Returns a named 2-tuple of `set`s: the first `set`, named `done`, contains the futures that completed (meaning that they either finished or were canceled) before `wait` returned; the second `set`, named `not_done`, contains as-yet-uncompleted futures.
	`timeout`, if not **None**, is a `float` number of seconds, the maximum time `wait` lets elapse before returning (when `timeout` is **None**, `wait` returns only when `return_when` is satisfied, no matter how much time elapses before that happens).
	`return_when` controls when, exactly, `wait` returns; it must be one of three constants supplied by the module `concurrent.futures`:
	
	`ALL_COMPLETED`
	Return when all futures finish or are canceled.
	
	`FIRST_COMPLETED`
	Return when any future finishes or is canceled.
	
	`FIRST_EXCEPTION`
	Return when any future raises an exception; should no future raise an exception, becomes equivalent to `ALL_COMPLETED`.

This version of `make_dict` illustrates how to use `concurrent.futures.as_completed` to process each task as it finishes (in contrast with the previous example using `Executor.map`, which always returns the tasks in the order in which they were submitted):

```
import concurrent.futures as cf

def make_dict(strings):
    with cf.ProcessPoolExecutor() as e:
        futures = [e.submit(runner, s) for s in strings]
        d = dict(f.result() for f in cf.as_completed(futures))
    return d
```

Threaded Program Architecture

A threaded program should always try to arrange for a *single* thread to "own" any object or subsystem that is external to the program (such as a file, a database, a GUI, or a network connection). Having multiple threads that deal with the same external object is possible, but can often create intractable problems.

When your threaded program must deal with some external object, devote a dedicated thread to just such dealings, and use a `Queue` object from which the external-interfacing thread gets work requests that other threads post. The external-interfacing thread returns results by putting them on one or more other `Queue` objects. The following example shows how to package this architecture into a general, reusable class, assuming that each unit of work on the external subsystem can be represented by a callable object:

```
import threading, queue

class ExternalInterfacing(threading.Thread):
    def __init__(self, external_callable, **kwds):
        super().__init__(**kwds)
        self.daemon = True
        self.external_callable = external_callable
        self.request_queue = queue.Queue()
        self.result_queue = queue.Queue()
        self.start()

    def request(self, *args, **kwds):
        """called by other threads as external_callable would be"""
        self.request_queue.put((args, kwds))
        return self.result_queue.get()

    def run(self):
        while True:
            a, k = self.request_queue.get()
            self.result_queue.put(self.external_callable(*a, **k))
```

Once some `ExternalInterfacing` object *`ei`* is instantiated, any other thread may call *`ei`*`.request` just as it would call `external_callable` absent such a mechanism (with or without arguments, as appropriate). The advantage of `ExternalInterfacing` is that calls to `external_callable` are *serialized*. This means that just one thread (the `Thread` object bound to *`ei`*) performs them, in some defined sequential order, without overlap, race conditions (hard-to-debug errors that depend on which thread just happens to "get there" first), or other anomalies that might otherwise result.

If you need to serialize several callables together, you can pass the callable as part of the work request, rather than passing it at the initialization of the class `ExternalInterfacing`, for greater generality. The following example shows this more general approach:

```python
import threading, queue

class Serializer(threading.Thread):
    def __init__(self, **kwds):
        super().__init__(**kwds)
        self.daemon = True
        self.work_request_queue = queue.Queue()
        self.result_queue = queue.Queue()
        self.start()

    def apply(self, callable, *args, **kwds):
        """called by other threads as `callable` would be"""
        self.work_request_queue.put((callable, args, kwds))
        return self.result_queue.get()

    def run(self):
        while True:
            callable, args, kwds = self.work_request_queue.get()
            self.result_queue.put(callable(*args, **kwds))
```

Once a `Serializer` object *`ser`* has been instantiated, any other thread may call *`ser`*`.apply(external_callable)` just as it would call `external_callable` without such a mechanism (with or without further arguments, as appropriate). The `Serializer` mechanism has the same advantages as `ExternalInterfacing`, except that all calls to the same or different callables wrapped by a single *`ser`* instance are now serialized.

The user interface of the whole program is an external subsystem, and thus should be dealt with by a single thread—specifically, the main thread of the program (this is mandatory for some user interface toolkits, and advisable even when using other toolkits that don't mandate it). A `Serializer` thread is therefore inappropriate. Rather, the program's main thread should deal only with user-interface issues, and farm out all actual work to worker threads that accept work requests on a `Queue` object and return results on another. A set of worker threads is generally known as a *thread pool*. As shown in the following example, all worker threads should share a single queue of requests and a single queue of results, since the main thread is the only one to post work requests and harvest results:

```python
import threading

class Worker(threading.Thread):
    IDlock = threading.Lock()
    request_ID = 0

    def __init__(self, requests_queue, results_queue, **kwds):
        super().__init__(**kwds)
        self.daemon = True
        self.request_queue = requests_queue
        self.result_queue = results_queue
        self.start()
```

```python
    def perform_work(self, callable, *args, **kwds):
        """called by main thread as `callable` would be,
                           but w/o return"""
        with self.IDlock:
            Worker.request_ID += 1
            self.request_queue.put(
                (Worker.request_ID, callable, args, kwds))
            return Worker.request_ID

    def run(self):
        while True:
            request_ID, callable, a, k = self.request_queue.get()
            self.result_queue.put((request_ID, callable(*a, **k)))
```

The main thread creates the two queues, then instantiates worker threads, as follows:

```python
import queue
requests_queue = queue.Queue()
results_queue = queue.Queue()
number_of_workers = 5
for i in range(number_of_workers):
    worker = Worker(requests_queue, results_queue)
```

Whenever the main thread needs to farm out work (execute some callable object that may take substantial time to produce results), the main thread calls `*worker*.perform_work(*callable*)`, much as it would call *`callable`* without such a mechanism (with or without further arguments, as appropriate). However, `perform_work` does not return the result of the call. Instead of the results, the main thread gets an ID that identifies the work request. When the main thread needs the results, it can keep track of that ID, since the request's results are tagged with the ID when they appear. The advantage of this mechanism is that the main thread never blocks waiting for the callable's execution to complete, but rather becomes ready again at once and can immediately return to its main business of dealing with the user interface.

The main thread must arrange to check the `results_queue`, since the result of each work request eventually appears there, tagged with the request's ID, when the worker thread that took that request from the queue finishes computing the result. How the main thread arranges to check for both user interface events and the results coming back from worker threads onto the results queue depends on what user interface toolkit is used, or—if the user interface is text-based—on the platform on which the program runs.

A widely applicable, though not always optimal, general strategy is for the main thread to *poll* (check the state of the results queue periodically). On most Unix-like platforms, the function `alarm` of the module `signal` allows polling. The `tkinter` GUI toolkit supplies an `after` method that is usable for polling. Some toolkits and platforms afford more effective strategies (such as letting a worker thread alert the main thread when it places some result on the results queue), but there is no generally available, cross-platform, cross-toolkit way to arrange for this. Therefore, the following artificial example ignores user interface events and just simulates work by evaluating random expressions, with random delays, on several worker threads, thus completing the previous example:

```
import random, time, queue, operator
# copy here class Worker as defined earlier

requests_queue = queue.Queue()
results_queue = queue.Queue()

number_of_workers = 3
workers = [Worker(requests_queue, results_queue)
           for i in range(number_of_workers)]
work_requests = {}

operations = {
    '+': operator.add,
    '-': operator.sub,
    '*': operator.mul,
    '/': operator.truediv,
    '%': operator.mod,
}

def pick_a_worker():
    return random.choice(workers)

def make_work():
    o1 = random.randrange(2, 10)
    o2 = random.randrange(2, 10)
    op = random.choice(list(operations))
    return f'{o1} {op} {o2}'

def slow_evaluate(expression_string):
    time.sleep(random.randrange(1, 5))
    op1, oper, op2 = expression_string.split()
    arith_function = operations[oper]
    return arith_function(int(op1), int(op2))

def show_results():
    while True:
        try:
            completed_id, results = results_queue.get_nowait()
        except queue.Empty:
            return
        work_expression = work_requests.pop(completed_id)
        print(f'Result {completed_id}: {work_expression} -> {results}')

for i in range(10):
    expression_string = make_work()
    worker = pick_a_worker()
    request_id = worker.perform_work(slow_evaluate, expression_string)
    work_requests[request_id] = expression_string
```

```python
        print(f'Submitted request {request_id}: {expression_string}')
        time.sleep(1.0)
        show_results()

    while work_requests:
        time.sleep(1.0)
        show_results()
```

Process Environment

The operating system supplies each process *P* with an *environment*, a set of variables whose names are strings (most often, by convention, uppercase identifiers) and whose values are also strings. In "Environment Variables" on page 22, we cover environment variables that affect Python's operations. Operating system shells offer ways to examine and modify the environment via shell commands and other means mentioned in that section.

> **Process Environments Are Self-Contained**
>
> The environment of any process *P* is determined when *P* starts. After startup, only *P* itself can change *P*'s environment. Changes to *P*'s environment affect only *P*: the environment is *not* a means of interprocess communication. Nothing that *P* does affects the environment of *P*'s parent process (the process that started *P*), nor that of any child process *previously* started from *P* and now running, or of any process unrelated to *P*. Child processes of *P* normally get a copy of *P*'s environment as it stands at the time *P* creates that process as a starting environment. In this narrow sense, changes to *P*'s environment do affect child processes that *P* starts *after* such changes.

The module `os` supplies the attribute `environ`, a mapping that represents the current process's environment. When Python starts, it initializes `os.environ` from the process environment. Changes to `os.environ` update the current process's environment if the platform supports such updates. Keys and values in `os.environ` must be strings. On Windows (but not on Unix-like platforms), keys into `os.environ` are implicitly uppercased. For example, here's how to try to determine which shell or command processor you're running under:

```python
import os
shell = os.environ.get('COMSPEC')
if shell is None:
    shell = os.environ.get('SHELL')
if shell is None:
    shell = 'an unknown command processor'
print('Running under ', shell)
```

When a Python program changes its environment (e.g., via `os.environ['X'] = 'Y'`), this does not affect the environment of the shell or command processor that started the program. As already explained—and for **all** programming languages, including Python—changes to a process's environment affect only the process itself, not other processes that are currently running.

Running Other Programs

You can run other programs via low-level functions in the `os` module, or (at a higher and usually preferable level of abstraction) with the `subprocess` module.

Using the Subprocess Module

The `subprocess` module supplies one very broad class: `Popen`, which supports many diverse ways for your program to run another program. The constructor for `Popen` has the signature:

`Popen` **`class`** `Popen(`*`args`*`, bufsize=0, executable=`**`None`**`, capture_output=`**`False`**`, stdin=`**`None`**`, stdout=`**`None`**`, stderr=`**`None`**`, preexec_fn=`**`None`**`, close_fds=`**`False`**`, shell=`**`False`**`, cwd=`**`None`**`, env=`**`None`**`, text=`**`None`**`, universal_newlines=`**`False`**`, startupinfo=`**`None`**`, creationflags=0)`

`Popen` starts a subprocess to run a distinct program, and creates and returns an object *p*, representing that subprocess. The *`args`* mandatory argument and the many optional named arguments control all details of how the subprocess is to run.

When any exception occurs during the subprocess creation (before the distinct program starts), `Popen` re-raises that exception in the calling process with the addition of an attribute named `child_traceback`, which is the Python traceback object for the subprocess. Such an exception would normally be an instance of `OSError` (or possibly `TypeError` or `ValueError` to indicate that you've passed to `Popen` an argument that's invalid in type or value).

---

subprocess.run() is a Convenience Wrapper Function for Popen

The subprocess module includes the `run` function that encapsulates a `Popen` instance and executes the most common processing flow on it. `run` accepts the same arguments as `Popen`'s constructor, runs the given command, waits for completion or timeout, and returns a `CompletedProcess` instance with attributes for the return code and stdout and `stderr` contents.

If the output of the command needs to be captured, the most common argument values would be to set the `capture_output` and `text` arguments to **`True`**.

What to run, and how

`args` is a sequence of strings: the first item is the path to the program to execute, and the following items, if any, are arguments to pass to the program (*`args`* can also be just a string, when you don't need to pass arguments). `executable`, when not **`None`**, overrides *`args`* in determining which program to execute. When `shell`

is **True**, executable specifies which shell to use to run the subprocess; when shell is **True** and executable is **None**, the shell used is */bin/sh* on Unix-like systems (on Windows, it's os.environ['COMSPEC']).

Subprocess files

stdin, stdout, and stderr specify the subprocess's standard input, output, and error files, respectively. Each may be PIPE, which creates a new pipe to/from the subprocess; **None**, meaning that the subprocess is to use the same file as this ("parent") process; or a file object (or file descriptor) that's already suitably open (for reading, for standard input; for writing, for standard output and standard error). stderr may also be subprocess.STDOUT, meaning that the subprocess's standard error must use the same file as its standard output.[4] When capture_output is true, you can not specify stdout, nor stderr: rather, behavior is just as if each was specified as PIPE. bufsize controls the buffering of these files (unless they're already open), with the same semantics as the same argument to the open function covered in "Creating a File Object with open" on page 323 (the default, 0, means "unbuffered"). When text (or its synonym universal_newlines, provided for backward compatibility) is true, stdout and stderr (unless they are already open) are opened as text files; otherwise, they're opened as binary files. When close_fds is true, all other files (apart from standard input, output, and error) are closed in the subprocess before the subprocess's program or shell executes.

Other, advanced arguments

When preexec_fn is not **None**, it must be a function or other callable object, and it gets called in the subprocess before the subprocess's program or shell is executed (only on Unix-like systems, where the call happens after fork and before exec).

When cwd is not **None**, it must be a string that gives the full path to an existing directory; the current directory gets changed to cwd in the subprocess before the subprocess's program or shell executes.

When env is not **None**, it must be a mapping with strings as both keys and values, and fully defines the environment for the new process; otherwise, the new process's environment is a copy of the environment currently active in the parent process.

startupinfo and creationflags are Windows-only arguments passed to the CreateProcess Win32 API call used to create the subprocess, for Windows-specific purposes (we do not cover them further in this book, which focuses almost exclusively on cross-platform uses of Python).

Attributes of subprocess.Popen instances

An instance *p* of the class Popen supplies the attributes listed in Table 15-17.

4 Just like **2>&1** would specify in a Unix-y shell command line.

Table 15-17. Attributes of an instance p of class Popen

`args`	Popen's *args* argument (string or sequence of strings).
`pid`	The process ID of the subprocess.
`return code`	`None` to indicate that the subprocess has not yet exited; otherwise, an integer: `0` for successful termination, `>0` for termination with an error code, or `<0` if the subprocess was killed by a signal.
`stderr, stdin, stdout`	When the corresponding argument to `Popen` was `subprocess.PIPE`, each of these attributes is a file object wrapping the corresponding pipe; otherwise, each of these attributes is **None**. Use the `communicate` method of *p*, rather than reading and writing to/from these file objects, to avoid possible deadlocks.

Methods of subprocess.Popen instances

An instance *p* of the class `Popen` supplies the methods listed in Table 15-18.

Table 15-18. Methods of an instance p of class Popen

`communicate`	`p.communicate(input=None, timeout=None)` Sends the string `input` as the subprocess's standard input (when `input` is not **None**), then reads the subprocess's standard output and error files into in-memory strings *so* and *se* until both files are finished, and finally waits for the subprocess to terminate and returns the pair (two-item tuple) `(so, se)`.
`poll`	`p.poll()` Checks if the subprocess has terminated; returns `p.returncode` if it has; otherwise, returns **None**.
`wait`	`p.wait(timeout=None)` Waits for the subprocess to terminate, then returns `p.returncode`. Should the subprocess not terminate within `timeout` seconds, raises `TimeoutExpired`.

Running Other Programs with the os Module

The best way for your program to run other processes is usually with the `subprocess` module, covered in the previous section. However, the `os` module (introduced in Chapter 11) also offers several lower-level ways to do this, which, in some cases, may be simpler to use.

The simplest way to run another program is through the function `os.system`, although this offers no way to *control* the external program. The `os` module also provides a number of functions whose names start with `exec`. These functions offer fine-grained control. A program run by one of the `exec` functions replaces the current program (i.e., the Python interpreter) in the same process. In practice, therefore, you use the `exec` functions mostly on platforms that let a process duplicate itself using `fork` (i.e., Unix-like platforms). `os` functions whose names start with `spawn` and `popen` offer intermediate simplicity and power: they are cross-platform and not quite as simple as `system`, but simple enough for many purposes.

The `exec` and `spawn` functions run a given executable file, given the executable file's path, arguments to pass to it, and optionally an environment mapping. The `system` and `popen` functions execute a command, which is a string passed to a new instance of the platform's default shell (typically */bin/sh* on Unix, *cmd.exe* on Windows). A *command* is a more general concept than an *executable file*, as it can include shell functionality (pipes, redirection, and built-in shell commands) using the shell syntax specific to the current platform.

`os` provides the functions listed in Table 15-19.

Table 15-19. Functions of the `os` module related to processes

`execl`, `execle`, `execlp`, `execv`, `execve`, `execvp`, `execvpe`	`execl(`*`path, *args`*`)`, `execle(`*`path, *args`*`)`, `execlp(`*`path,*args`*`)`, `execv(`*`path, args`*`)`, `execve(`*`path, args, env`*`)`, `execvp(`*`path, args`*`)`, `execvpe(`*`path, args, env`*`)` Run the executable file (program) indicated by string *`path`*, replacing the current program (i.e., the Python interpreter) in the current process. The distinctions encoded in the function names (after the prefix `exec`) control three aspects of how the new program is found and run: • Does *`path`* have to be a complete path to the program's executable file, or can the function accept a name as the *`path`* argument and search for the executable in several directories, as operating system shells do? `execlp`, `execvp`, and `execvpe` can accept a *`path`* argument that is just a filename rather than a complete path. In this case, the functions search for an executable file of that name in the directories listed in `os.environ['PATH']`. The other functions require *`path`* to be a complete path to the executable file. • Does the function accept arguments for the new program as a single sequence argument *`args`*, or as separate arguments to the function? Functions whose names start with `execv` take a single argument *`args`* that is the sequence of arguments to use for the new program. Functions whose names start with `execl` take the new program's arguments as separate arguments (`execle`, in particular, uses its last argument as the environment for the new program). • Does the function accept the new program's environment as an explicit mapping argument *`env`*, or implicitly use `os.environ`? `execle`, `execve`, and `execvpe` take an argument *`env`* that is a mapping to use as the new program's environment (keys and values must be strings), while the other functions use `os.environ` for this purpose. Each `exec` function uses the first item in *`args`* as the name under which the new program is told it's running (for example, `argv[0]` in a C program's `main`); only `args[1:]` are arguments proper to the new program.

popen	`popen(`*`cmd`*`, mode='r', buffering=-1)` Runs the string command *`cmd`* in a new process *P* and returns a file-like object *`f`* that wraps a pipe to *P*'s standard input or from *P*'s standard output (depending on `mode`); *`f`* uses text streams in both directions rather than raw bytes. `mode` and `buffering` have the same meaning as for Python's `open` function, covered in "Creating a File Object with open" on page 323. When `mode` is `'r'` (the default), *`f`* is read-only and wraps *P*'s standard output. When `mode` is `'w'`, *`f`* is write-only and wraps *P*'s standard input. The key difference of *`f`* from other file-like objects is the behavior of method *`f`*`.close`. *`f`*`.close` waits for *P* to terminate and returns **None**, as `close` methods of file-like objects normally do, when *P*'s termination is successful. However, if the operating system associates an integer error code *`c`* with *P*'s termination, indicating that *P*'s termination was unsuccessful, *`f`*`.close` returns *`c`*. On Windows systems, `c` is a signed integer return code from the child process.

spawnv, spawnve	`spawnv(`*`mode, path, args`*`)`,
	`spawnve(`*`mode, path, args, env`*`)`
	These functions run the program indicated by *`path`* in a new process *P*, with the arguments passed as sequence *`args`*. `spawnve` uses mapping *`env`* as *P*'s environment (both keys and values must be strings), while `spawnv` uses `os.environ` for this purpose. On Unix-like platforms only, there are other variations of `os.spawn`, corresponding to variations of `os.exec`, but `spawnv` and `spawnve` are the only two that also exist on Windows.
	`mode` must be one of two attributes supplied by the `os` module: `os.P_WAIT` indicates that the calling process waits until the new process terminates, while `os.P_NOWAIT` indicates that the calling process continues executing simultaneously with the new process. When *`mode`* is `os.P_WAIT`, the function returns the termination code *`c`* of *P*: `0` indicates successful termination, *`c`* < `0` indicates *P* was killed by a *signal*, and *`c`* > `0` indicates normal but unsuccessful termination. When *`mode`* is `os.P_NOWAIT`, the function returns *P*'s process ID (or, on Windows, *P*'s process handle). There is no cross-platform way to use *P*'s ID or handle; platform-specific ways (not covered further in this book) include `os.waitpid` on Unix-like platforms, and third-party extension package `pywin32` on Windows.
	For example, suppose you want your interactive program to give the user a chance to edit a text file that your program is about to read and use. You must have previously determined the full path to the user's favorite text editor, such as *c:\\windows\\notepad.exe* on Windows or */usr/bin/vim* on a Unix-like platform. Say that this path string is bound to the variable `editor`, and the path of the text file you want to let the user edit is bound to `textfile`:
	`import os`
	`os.spawnv(os.P_WAIT, editor, (editor, textfile))`
	The first item of the argument *args* is passed to the program being spawned as "the name under which the program is being invoked." Most programs don't look at this, so you can usually place just about any string here. Just in case the editor program does look at this special first argument (some versions of Vim, for example, do), passing the same string editor that is used as the second argument to `os.spawnv` is the simplest and most effective approach.

`system`	`system(`*`cmd`*`)` Runs the string command *`cmd`* in a new process and returns `0` when the new process terminates successfully. When the new process terminates unsuccessfully, `system` returns an integer error code not equal to `0`. (Exactly what error codes may be returned depends on the command you're running: there's no widely accepted standard for this.)

The mmap Module

The `mmap` module supplies memory-mapped file objects. An `mmap` object behaves similarly to a bytestring, so you can often pass an `mmap` object where a bytestring is expected. However, there are differences:

- An `mmap` object does not supply the methods of a string object.
- An `mmap` object is mutable, like a `bytearray`, while `bytes` objects are immutable.
- An `mmap` object also corresponds to an open file, and behaves polymorphically to a Python file object (as covered in "File-Like Objects and Polymorphism" on page 327).

An `mmap` object *`m`* can be indexed or sliced, yielding bytestrings. Since *`m`* is mutable, you can also assign to an indexing or slicing of *`m`*. However, when you assign to a slice of *`m`*, the righthand side of the assignment statement must be a bytestring of exactly the same length as the slice you're assigning to. Therefore, many of the useful tricks available with list slice assignment (covered in "Modifying a list" on page 66) do not apply to `mmap` slice assignment.

The `mmap` module supplies a factory function, slightly different on Unix-like systems and on Windows:

`mmap`	*Windows:* `mmap(`*`filedesc`*`, `*`length`*`, tagname='', access=`**`None`**`, offset=`**`None`**`)` *Unix:* `mmap(`*`filedesc`*`, `*`length`*`, flags=MAP_SHARED, prot=PROT_READ|PROT_WRITE, access=`**`None`**`, offset=0)` Creates and returns an `mmap` object *`m`* that maps into memory the first *`length`* bytes of the file indicated by file descriptor *`filedesc`*. *`filedesc`* must be a file descriptor opened for both reading and writing, except, on Unix-like platforms, when the argument `prot` requests only reading or only writing. (File descriptors are covered in "File descriptor operations" on page 351.) To get an `mmap` object *`m`* for a Python file object *`f`*, use *`m`*`=mmap.mmap(`*`f`*`.fileno(), `*`length`*`)`. *`filedesc`* can be `-1` to map anonymous memory. On Windows, all memory mappings are readable and writable, and shared among processes, so all processes with a memory mapping on a file can see changes made by other processes. On Windows only, you can pass a string `tagname` to give an explicit *tag name* for the memory mapping. This tag name lets you have several separate memory mappings on the same file, but this is rarely necessary. Calling `mmap` with only two arguments has the advantage of keeping your code portable between Windows and Unix-like platforms.

`mmap` *(cont.)*	On Unix-like platforms only, you can pass `mmap.MAP_PRIVATE` as `flags` to get a mapping that is private to your process and copy-on-write. `mmap.MAP_SHARED`, the default, gets a mapping that is shared with other processes so that all processes mapping the file can see changes made by one process (the same as on Windows). You can pass `mmap.PROT_READ` as the `prot` argument to get a mapping that you can only read, not write. Passing `mmap.PROT_WRITE` gets a mapping that you can only write, not read. The default, the bitwise OR `mmap.PROT_READ|mmap.PROT_WRITE`, gets a mapping you can both read and write. You can pass the named argument `access` instead of `flags` and `prot` (it's an error to pass both `access` and either or both of the other two arguments). The value for `access` can be one of `ACCESS_READ` (read-only), `ACCESS_WRITE` (write-through, the default on Windows), or `ACCESS_COPY` (copy-on-write). You can pass the named argument `offset` to start the mapping after the beginning of the file; `offset` must be an `int >= 0`, a multiple of `ALLOCATIONGRANULARITY` (or, on Unix, of `PAGESIZE`).

Methods of mmap Objects

An `mmap` object *m* supplies the methods detailed in Table 15-20.

Table 15-20. Methods of an instance m of mmap

`close`	`m.close()` Closes *m*'s file.
`find`	`m.find(sub, start=0, end=None)` Returns the lowest `i >= start` such that `sub == m[i:i+len(sub)]` (and `i+len(sub)-1 <= end`, when you pass `end`). If no such `i` exists, `m.find` returns `-1`. This is the same behavior as the `find` method of `str`, covered in Table 9-1.
`flush`	`m.flush([offset, n])` Ensures that all changes made to *m* exist in *m*'s file. Until you call `m.flush`, it's unsure if the file reflects the current state of *m*. You can pass a starting byte offset `offset` and a byte count *n* to limit the flushing effect's guarantee to a slice of *m*. Pass both arguments, or neither: it's an error to call `m.flush` with just one argument.
`move`	`m.move(dstoff, srcoff, n)` Like the slice assignment `m[dstoff:dstoff+n] = m[srcoff:srcoff+n]`, but potentially faster. The source and destination slices can overlap. Apart from such potential overlap, `move` does not affect the source slice (i.e., the `move` method *copies* bytes but does not *move* them, despite the method's name).
`read`	`m.read(n)` Reads and returns a byte string *s* containing up to *n* bytes starting from *m*'s file pointer, then advances *m*'s file pointer by `len(s)`. If there are fewer than *n* bytes between *m*'s file pointer and *m*'s length, returns the bytes available. In particular, if *m*'s file pointer is at the end of *m*, returns the empty bytestring `b''`.

`read_byte`	`m.read_byte()` Returns a byte string of length `1` containing the byte at *m*'s file pointer, then advances *m*'s file pointer by `1`. `m.read_byte()` is similar to `m.read(1)`. However, if *m*'s file pointer is at the end of *m*, `m.read(1)` returns the empty string `b''` and doesn't advance, while `m.read_byte()` raises a `ValueError` exception.
`readline`	`m.readline()` Reads and returns, as a bytestring, one line from *m*'s file, from *m*'s current file pointer up to the next `'\n'`, included (or up to the end of *m* if there is no `'\n'`), then advances *m*'s file pointer to point just past the bytes just read. If *m*'s file pointer is at the end of *m*, `readline` returns the empty string `b''`.
`resize`	`m.resize(n)` Changes the length of *m* so that `len(m)` becomes *n*. Does not affect the size of *m*'s file. *m*'s length and the file's size are independent. To set *m*'s length to be equal to the file's size, call `m.resize(m.size())`. If *m*'s length is larger than the file's size, *m* is padded with null bytes (`\x00`).
`rfind`	`rfind(sub, start=0, end=None)` Returns the highest `i >= start` such that *sub* == `m[i:i+len(sub)]` (and `i+len(sub)-1 <= end`, when you pass `end`). If no such `i` exists, `m.rfind` returns `-1`. This is the same as the `rfind` method of string objects, covered in Table 9-1.

`seek`	`m.seek(pos, how=0)`
	Sets *m*'s file pointer to the integer byte offset *pos*, relative to the position indicated by `how`:
	
	`0` *or* `os.SEEK_SET`
	    Offset is relative to start of *m*
	
	`1` *or* `os.SEEK_CUR`
	    Offset is relative to *m*'s current file pointer
	
	`2` *or* `os.SEEK_END`
	    Offset is relative to end of *m*
	
	A `seek` trying to set *m*'s file pointer to a negative offset, or to an offset beyond *m*'s length, raises a `ValueError` exception.

`size`	`m.size()` Returns the length (number of bytes) of *m*'s file (not the length of *m* itself). To get the length of *m*, use `len(m)`.
`tell`	`m.tell()` Returns the current position of *m*'s file pointer, a byte offset within *m*'s file.
`write`	`m.write(b)` Writes the bytes in bytestring *b* into *m* at the current position of *m*'s file pointer, overwriting the bytes that were there, and then advances *m*'s file pointer by `len(b)`. If there aren't at least `len(b)` bytes between *m*'s file pointer and the length of *m*, `write` raises a `ValueError` exception.

write_byte	*m*.write_byte(*byte*) Writes *byte*, which must be an int, into mapping *m* at the current position of *m*'s file pointer, overwriting the byte that was there, and then advances *m*'s file pointer by 1. *m*.write_byte(*x*) is similar to *m*.write(*x*.to_bytes(1, 'little')). However, if *m*'s file pointer is at the end of *m*, *m*.write_byte(*x*) silently does nothing, while *m*.write(*x*.to_bytes(1, 'little')) raises a ValueError exception. Note that this is the reverse of the relationship between read and read_byte at end-of-file: write and read_byte may raise ValueError, while read and write_byte never do.

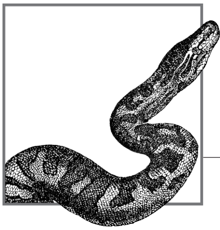
Using mmap Objects for IPC

Processes communicate using mmap pretty much the same way they communicate using files: one process writes data, and another process later reads the same data back. Since an mmap object has an underlying file, you can have some processes doing I/O on the file (as covered in "The io Module" on page 322), while others use mmap on the same file. Choose between mmap and I/O on file objects on the basis of convenience: functionality is the same, performance is roughly equivalent. For example, here is a simple program that repeatedly uses file I/O to make the contents of a file equal to the last line interactively typed by the user:

```
fileob = open('xxx','wb')
while True:
    data = input('Enter some text:')
    fileob.seek(0)
    fileob.write(data.encode())
    fileob.truncate()
    fileob.flush()
```

And here is another simple program that, when run in the same directory as the former, uses mmap (and the time.sleep function, covered in Table 13-2) to check every second for changes to the file and print out the file's new contents, if there have been any changes:

```
import mmap, os, time
mx = mmap.mmap(os.open('xxx', os.O_RDWR), 1)
last = None
while True:
    mx.resize(mx.size())
    data = mx[:]
    if data != last:
        print(data)
        last = data
    time.sleep(1)
```



16 Numeric Processing

You can perform some numeric computations with operators (covered in "Numeric Operations" on page 60) and built-in functions (covered in "Built-in Functions" on page 251). Python also provides modules that support additional numeric computations, covered in this chapter: `math` and `cmath`, `statistics`, `operator`, `random` and `secrets`, `fractions`, and `decimal`. Numeric processing often requires, more specifically, the processing of *arrays* of numbers; this topic is covered in "Array Processing" on page 502, focusing on the standard library module `array` and popular third-party extension NumPy. Finally, "Additional numeric packages" on page 510 lists several additional numeric processing packages produced by the Python community. Most examples in this chapter assume you've imported the appropriate module; **`import`** statements are only included where the situation might be unclear.

Floating-Point Values

Python represents real numeric values (that is, those that are not integers) using variables of type `float`. Unlike integers, computers can rarely represent `floats` exactly, due to their internal implementation as a fixed-size binary integer *significand* (often incorrectly called "mantissa") and a fixed-size binary integer exponent. `floats` have several limitations (some of which can lead to unexpected results).

For most everyday applications, `floats` are sufficient for arithmetic, but they are limited in the number of decimal places they can represent:

```
>>> f = 1.1 + 2.2 - 3.3  # f should be equal to 0
>>> f

4.440892098500626e-16
```

They are also limited in the range of integer values they can accurately store (in the sense of being able to distinguish one from the next largest or smallest integer value):

```
>>> f = 2 ** 53
>>> f

9007199254740992

>>> f + 1

9007199254740993     # integer arithmetic is not bounded

>>> f + 1.0

9007199254740992.0   # float conversion loses integer precision at 2**53
```

Always keep in mind that `floats` are not entirely precise, due to their internal representation in the computer. The same consideration applies to `complex` numbers.

> **Don't Use == Between Floating-Point or Complex Numbers**
> Given that floating-point numbers and operations only approximate the behavior of mathematical "real numbers," it seldom makes sense to check two `floats` *x* and *y* for exact equality. Tiny variations in how each was computed can easily result in unexpected differences.

For testing floating-point or complex numbers for equality, use the function `isclose` exported by the built-in module `math`. The following code illustrates why:

```
>>> import math
>>> f = 1.1 + 2.2 - 3.3  # f intuitively equal to 0
>>> f == 0

False

>>> f

4.440892098500626e-16

>>> # default tolerance fine for this comparison
>>> math.isclose(-1, f-1)

True
```

For some values, you may have to set the tolerance value explicitly (this is *always* necessary when you're comparing with `0`):

```
>>> # near-0 comparison with default tolerances
>>> math.isclose(0, f)

False

>>> # must use abs_tol for comparison with 0
>>> math.isclose(0, f, abs_tol=1e-15)

True
```

You can also use `isclose` for safe looping.

Don't Use a float as a Loop Control Variable

A common error is to use a floating-point value as the control variable of a loop, assuming that it will eventually equal some ending value, such as `0`. Instead, it most likely will end up looping forever.

The following loop, expected to loop five times and then end, will in fact loop forever:

```
>>> f = 1
>>> while f != 0:
...     f -= 0.2
```

Even though `f` started as an `int`, it's now a `float`. This code shows why:

```
>>> 1-0.2-0.2-0.2-0.2-0.2  # should be 0, but...
5.551115123125783e-17
```

Even using the inequality operator `>` results in incorrect behavior, looping six times instead of five (since the residual `float` value is still greater than `0`):

```
>>> f = 1
>>> count = 0
>>> while f > 0:
...     count += 1
...     f -= 0.2
>>> print(count)
6   # one loop too many!
```

If instead you use `math.isclose` for comparing *f* with `0`, the **`for`** loop repeats the correct number of times:

```
>>> f = 1
>>> count = 0
>>> while not math.isclose(0,f,abs_tol=1e-15):
...     count += 1
...     f -= 0.2
>>> print(count)
5   # just right this time!
```

In general, try to use an `int` for a loop's control variable, rather than a `float`.

Finally, mathematical operations that result in very large `floats` will often cause an `OverflowError`, or Python may return them as `inf` (infinity). The maximum `float` value usable on your computer is `sys.float_info.max`: on 64-bit computers, it's `1.7976931348623157e+308`. This may cause unexpected results when doing math using very large numbers. When you need to work with very large numbers, we recommend using the `decimal` module or third-party `gmpy` instead.

The math and cmath Modules

The `math` module supplies mathematical functions for working with floating-point numbers; the `cmath` module supplies equivalent functions for complex numbers. For example, `math.sqrt(-1)` raises an exception, but `cmath.sqrt(-1)` returns `1j`.

Just like for any other module, the cleanest, most readable way to use these is to have, for example, `import math` at the top of your code, and explicitly call, say, `math.sqrt` afterward. However, if your code includes a large number of calls to the modules' well-known mathematical functions, you might (though it may lose some clarity and readability) either use `from math import *`, or use `from math import sqrt`, and afterward just call `sqrt`.

Each module exposes three `float` attributes bound to the values of fundamental mathematical constants, `e`, `pi`, and tau, and a variety of functions, including those shown in Table 16-1. The `math` and `cmath` modules are not fully symmetric, so for each method the table indicates whether it is in `math`, `cmath`, or both. All examples assume you have imported the appropriate module.

Table 16-1. Methods and attributes of the `math` and `cmath` modules

		math	cmath
`acos`, `asin`, `atan`, `cos`, `sin`, `tan`	`acos(x)`, etc. Return the trigonometric functions arccosine, arcsine, arctangent, cosine, sine, or tangent, respectively, of *x*, given in radians.	✓	✓
`acosh`, `asinh`, `atanh`, `cosh`, `sinh`, `tanh`	`acosh(x)`, etc. Return the arc hyperbolic cosine, arc hyperbolic sine, arc hyperbolic tangent, hyperbolic cosine, hyperbolic sine, or hyperbolic tangent, respectively, of *x*, given in radians.	✓	✓

`atan2`	`atan2(y, x)`
	Like `atan(y/x)`, except that `atan2` properly takes into account the signs of both arguments. For example:
	`>>> math.atan(-1./-1.)`
	`0.7853981633974483`
	`>>> math.atan2(-1., -1.)`
	`-2.356194490192345`
	When *x* equals 0, `atan2` returns `π/2`, while dividing by *x* would raise `ZeroDivisionError`.
		✓	

`cbrt`	`cbrt(x)` **3.11+** Returns the cube root of *x*.	✓	
`ceil`	`ceil(x)` Returns `float(i)`, where `i` is the smallest integer such that `i>=x`.	✓	

		math	cmath
comb	comb(*n*, *k*) **3.8+** Returns the number of *combinations* of *n* items taken *k* items at a time, regardless of order. When counting the number of combinations taken from three items *A*, *B*, and *C*, two at a time, comb(3, 2) returns 3 because, for example, *A-B* and *B-A* are considered the *same* combination (contrast this with perm, later in this table). Raises ValueError when *k* or *n* is negative; raises TypeError when *k* or *n* is not an int. When *k*>*n*, just returns 0, raising no exceptions.	✓	
copysign	copysign(*x*, *y*) Returns the absolute value of *x* with the sign of *y*.	✓	
degrees	degrees(*x*) Returns the degree measure of the angle *x* given in radians.	✓	
dist	dist(*pt0*, *pt1*) **3.8+** Returns the Euclidean distance between two *n*-dimensional points, where each point is represented as a sequence of values (coordinates). Raises ValueError if *pt0* and *pt1* are sequences of different lengths.	✓	
e	The mathematical constant *e* (2.718281828459045).	✓	✓
erf	erf(*x*) Returns the error function of *x* as used in statistical calculations.	✓	
erfc	erfc(*x*) Returns the complementary error function at *x*, defined as 1.0 - erf(*x*).	✓	
exp	exp(*x*) Returns e^x.	✓	✓
exp2	exp2(*x*) **3.11+** Returns 2^x.	✓	
expm1	expm1(*x*) Returns e^x - 1. Inverse of log1p.	✓	
fabs	fabs(*x*) Returns the absolute value of *x*. Always returns a float, even if *x* is an int (unlike the built-in abs function).	✓	
factorial	factorial(*x*) Returns the factorial of *x*. Raises ValueError when *x* is negative, and TypeError when *x* is not integral.	✓	
floor	floor(*x*) Returns float(*i*), where *i* is the greatest integer such that *i*<=*x*.	✓	
fmod	fmod(*x*, *y*) Returns the float *r*, with the same sign as *x*, such that *r*==*x*-*n***y* for some integer *n*, and abs(*r*)<abs(*y*). Like *x*%*y*, except that, when *x* and *y* differ in sign, *x*%*y* has the same sign as *y*, not the same sign as *x*.	✓	

Numeric Processing

		math	cmath
`frexp`	`frexp(`*x*`)` Returns a pair `(`*m*`,` *e*`)` where *m* is a floating-point number and *e* is an integer such that *x*`==`*m*`*(2**e)` and `0.5<=abs(`*m*`)<1`,[a] except that `frexp(0)` returns `(0.0, 0)`.	✓	
`fsum`	`fsum(`*iterable*`)` Returns the floating-point sum of the values in *iterable* to greater precision than the `sum` built-in function.	✓	
`gamma`	`gamma(`*x*`)` Returns the Gamma function evaluated at *x*.	✓	
`gcd`	`gcd(`*x*`,` *y*`)` Returns the greatest common divisor of *x* and *y*. When *x* and *y* are both zero, returns `0`. (**3.9+** `gcd` can accept any number of values; `gcd()` without arguments returns `0`.)	✓	
`hypot`	`hypot(`*x*`,` *y*`)` Returns `sqrt(`*x*`*`*x*`+`*y*`*`*y*`)`. (**3.8+** `hypot` can accept any number of values, to compute a hypotenuse length in *n* dimensions.)	✓	
`inf`	A floating-point positive infinity, like `float('inf')`.	✓	✓
`infj`	A `complex` imaginary infinity, equal to `complex(0, float('inf'))`.		✓
`isclose`	`isclose(`*x*`,` *y*`, rel_tol=1e-09, abs_tol=0.0)` Returns **`True`** when *x* and *y* are approximately equal, within relative tolerance `rel_tol`, with minimum absolute tolerance of `abs_tol`; otherwise, returns **`False`**. Default is `rel_tol` within nine decimal digits. `rel_tol` must be greater than `0`. `abs_tol` is used for comparisons near zero: it must be at least `0.0`. NaN is not considered close to any value (including NaN itself); each of `-inf` and `inf` is only considered close to itself. Except for behavior at +/– `inf`, `isclose` is like: `abs(x-y) <= max(rel_tol*max(abs(x), abs(y)),abs_tol)`	✓	✓
`isfinite`	`isfinite(`*x*`)` Returns **`True`** when *x* (in `cmath`, both the real and imaginary parts of *x*) is neither infinity nor NaN; otherwise, returns **`False`**.	✓	✓
`isinf`	`isinf(`*x*`)` Returns **`True`** when *x* (in `cmath`, either the real or imaginary part of *x*, or both) is positive or negative infinity; otherwise, returns **`False`**.	✓	✓
`isnan`	`isnan(`*x*`)` Returns **`True`** when *x* (in `cmath`, either the real or imaginary part of *x*, or both) is NaN; otherwise, returns **`False`**.	✓	✓
`isqrt`	`isqrt(`*x*`)` **3.8+** Returns `int(sqrt(`*x*`))`.	✓	

		math	cmath
`lcm`	`lcm(x, ...)` 3.9+ Returns the least common multiple of the given `int`s. If not all values are `int`s, raises `TypeError`.	✓	
`ldexp`	`ldexp(x, i)` Returns `x*(2**i)` (*i* must be an `int`; when *i* is a `float`, `ldexp` raises `TypeError`). Inverse of `frexp`.	✓	
`lgamma`	`lgamma(x)` Returns the natural logarithm of the absolute value of the Gamma function evaluated at *x*.	✓	
`log`	`log(x)` Returns the natural logarithm of *x*.	✓	✓
`log10`	`log10(x)` Returns the base-10 logarithm of *x*.	✓	✓
`log1p`	`log1p(x)` Returns the natural logarithm of `1+x`. Inverse of `expm1`.	✓	
`log2`	`log2(x)` Returns the base-2 logarithm of *x*.	✓	
`modf`	`modf(x)` Returns a pair `(f, i)` with the fractional and integer parts of *x*, meaning two `float`s with the same sign as *x* such that `i==int(i)` and `x==f+i`.	✓	
`nan`	`nan` A floating-point "Not a Number" (`NaN`) value, like `float('nan')` or `complex('nan')`.	✓	✓
`nanj`	A complex number with a `0.0` real part and floating-point "Not a Number" (`NaN`) imaginary part.		✓
`nextafter`	`nextafter(a, b)` 3.9+ Returns the next higher or lower `float` value from *a* in the direction of *b*.	✓	
`perm`	`perm(n, k)` 3.8+ Returns the number of *permutations* of *n* items taken *k* items at a time, where selections of the same items but in differing order are counted separately. When counting the number of permutations of three items *A*, *B*, and *C*, taken two at a time, `perm(3, 2)` returns `6`, because, for example, *A-B* and *B-A* are considered to be different permutations (contrast this with `comb`, earlier in this table). Raises `ValueError` when *k* or *n* is negative; raises `TypeError` when *k* or *n* is not an `int`.	✓	
`pi`	The mathematical constant π, 3.141592653589793.	✓	✓

Numeric Processing

		math	cmath
phase	`phase(x)` Returns the *phase* of *x*, a `float` in the range (–π, π). Like `math.atan2(x.imag, x.real)`. See "Conversions to and from polar coordinates" in the online docs for details.		✓
polar	`polar(x)` Returns the polar coordinate representation of *x*, as a pair `(r, phi)` where *r* is the modulus of *x* and *phi* is the phase of *x*. Like `(abs(x), cmath.phase(x))`. See "Conversions to and from polar coordinates" in the online docs for details.		✓
pow	`pow(x, y)` Returns `float(x)**float(y)`. For large `int` values of *x* and *y*, to avoid `OverflowError` exceptions, use `x**y` or the pow built-in function instead (which does not convert to `float`s).	✓	
prod	`prod(seq, start=1)` **3.8+** Returns the product of all values in the sequence, beginning with the given `start` value, which defaults to `1`. If *seq* is empty, returns the start value.	✓	
radians	`radians(x)` Returns the radian measure of the angle *x* given in degrees.	✓	
rect	`rect(r, phi)` Returns the `complex` value representing the polar coordinates `(r, phi)` converted to rectangular coordinates as `(x + yj)`.		✓
remainder	`remainder(x, y)` Returns the signed remainder from dividing `x/y` (the result may be negative if *x* or *y* is negative).	✓	
sqrt	`sqrt(x)` Returns the square root of *x*.	✓	✓
tau	The mathematical constant τ = 2π, or 6.283185307179586.	✓	✓
trunc	`trunc(x)` Returns *x* truncated to an `int`.	✓	
ulp	`ulp(x)` **3.9+** Returns the least significant bit of floating-point value *x*. For positive values, equals `math.nextafter(x, x+1) - x`. For negative values, equals `ulp(-x)`. If *x* is `NaN` or `inf`, returns *x*. `ulp` stands for *unit of least precision*.	✓	

[a] Formally, *m* is the significand, and *e* is the exponent. Used to render a cross-platform portable representation of a floating-point value.

The statistics Module

The `statistics` module supplies the class `NormalDist` to perform distribution analytics, and the functions listed in Table 16-2 to compute common statistics.

Table 16-2. Functions of the `statistics` module (with functions added in versions 3.8 and 3.10)

	3.8+	3.10+
harmonic_mean	fmean	correlation
mean	geometric_mean	covariance
median	multimode	linear_regression
median_grouped	quantiles	
median_high	NormalDist	
median_low		
mode		
pstdev		
pvariance		
stdev		
variance		

The online docs contain detailed information on the signatures and use of these functions.

The operator Module

The `operator` module supplies functions that are equivalent to Python's operators. These functions are handy in cases where callables must be stored, passed as arguments, or returned as function results. The functions in `operator` have the same names as the corresponding special methods (covered in "Special Methods" on page 141). Each function is available with two names, with and without "dunder" (leading and trailing double underscores): for example, both `operator.add(a, b)` and `operator.__add__(a, b)` return `a + b`.

Matrix multiplication support has been added for the infix operator `@`, but you must implement it by defining your own `__matmul__`, `__rmatmul__`, and/or `__imatmul__` methods; NumPy currently supports `@` (but, as of this writing, not yet `@=`) for matrix multiplication.

Table 16-3 lists some of the functions supplied by the `operator` module. For detailed information on these functions and their use, see the online docs.

Table 16-3. Functions supplied by the `operator` module

Function	Signature	Behaves like
abs	abs(*a*)	abs(*a*)
add	add(*a*, *b*)	*a* + *b*
and_	and_(*a*, *b*)	*a* & *b*
concat	concat(*a*, *b*)	*a* + *b*
contains	contains(*a*, *b*)	*b* **in** *a*
countOf	countOf(*a*, *b*)	*a*.count(*b*)
delitem	delitem(*a*, *b*)	**del** *a*[*b*]
delslice	delslice(*a*, *b*, *c*)	**del** *a*[*b*:*c*]
eq	eq(*a*, *b*)	*a* == *b*
floordiv	floordiv(*a*, *b*)	*a* // *b*
ge	ge(*a*, *b*)	*a* >= *b*
getitem	getitem(*a*, *b*)	*a*[*b*]
getslice	getslice(*a*, *b*, *c*)	*a*[*b*:*c*]
gt	gt(*a*, *b*)	*a* > *b*
index	index(*a*)	*a*.__index__()
indexOf	indexOf(*a*, *b*)	*a*.index(*b*)
invert, inv	invert(*a*), inv(*a*)	~*a*
is_	is_(*a*, *b*)	*a* **is** *b*
is_not	is_not(*a*, *b*)	*a* **is not** *b*
le	le(*a*, *b*)	*a* <= *b*
lshift	lshift(*a*, *b*)	*a* << *b*
lt	lt(*a*, *b*)	*a* < *b*
matmul	matmul(*m1*, *m2*)	*m1* @ *m2*
mod	mod(*a*, *b*)	*a* % *b*
mul	mul(*a*, *b*)	*a* * *b*
ne	ne(*a*, *b*)	*a* != *b*
neg	neg(*a*)	-*a*
not_	not_(*a*)	**not** *a*
or_	or_(*a*, *b*)	*a* | *b*
pos	pos(*a*)	+*a*
pow	pow(*a*, *b*)	a ** b
repeat	repeat(*a*, *b*)	*a* * *b*

Function	Signature	Behaves like
rshift	rshift(*a*, *b*)	*a* >> *b*
setitem	setitem(*a*, *b*, *c*)	*a*[*b*] = *c*
setslice	setslice(*a*, *b*, *c*, *d*)	*a*[*b*:*c*] = *d*
sub	sub(*a*, *b*)	*a* - *b*
truediv	truediv(*a*, *b*)	*a*/*b* *# no truncation*
truth	truth(*a*)	bool(*a*), **not not** a
xor	xor(*a*, *b*)	*a* ^ *b*

The operator module also supplies additional higher-order functions, listed in Table 16-4. Three of these functions, attrgetter, itemgetter, and methodcaller, return functions suitable for passing as named argument key to the sort method of lists, the sorted, min, and max built-in functions, and several functions in standard library modules, such as heapq and itertools (discussed in Chapter 8).

Table 16-4. Higher-order functions supplied by the operator module

attrgetter	attrgetter(*attr*), attrgetter(**attrs*) Returns a callable *f* such that *f*(*o*) is the same as getattr(*o*, *attr*). The string *attr* can include dots (.), in which case the callable result of attrgetter calls getattr repeatedly. For example, operator.attrgetter('a.b') is equivalent to **lambda** *o*: getattr(getattr(*o*, 'a'), 'b'). When you call attrgetter with multiple arguments, the resulting callable extracts each attribute thus named and returns the resulting tuple of values.
itemgetter	itemgetter(*key*), itemgetter(**keys*) Returns a callable *f* such that *f*(*o*) is the same as getitem(*o*, *key*). When you call itemgetter with multiple arguments, the resulting callable extracts each item thus keyed and returns the resulting tuple of values. For example, say that *L* is a list of lists, with each sublist at least three items long: you want to sort *L*, in place, based on the third item of each sublist, with sublists having equal third items sorted by their first items. The simplest way to do this is: `L.sort(key=operator.itemgetter(2, 0))`
length_hint	length_hint(*iterable*, default=0) Used to try to preallocate storage for items in *iterable*. Calls object *iterable*'s __len__ method to try to get an exact length. If __len__ is not implemented, then Python tries calling *iterable*'s __length_hint__ method. If this is also not implemented, length_hint returns the given default. Any mistake in using this "hint" helper may result in a performance issue, but not in silent, incorrect behavior.
method caller	methodcaller(*methodname*, args...) Returns a callable *f* such that *f*(*o*) is the same as o.*methodname*(args, ...). The optional args may be given as positional or named arguments.

Numeric Processing

Random and Pseudorandom Numbers

The `random` module of the standard library generates pseudorandom numbers with various distributions. The underlying uniform pseudorandom generator uses the powerful, popular Mersenne Twister algorithm, with a (huge!) period of length $2^{19937}-1$.

The random Module

All functions of the `random` module are methods of one hidden global instance of the class `random.Random`. You can instantiate `Random` explicitly to get multiple generators that do not share state. Explicit instantiation is advisable if you require random numbers in multiple threads (threads are covered in Chapter 15). Alternatively, instantiate `SystemRandom` if you require higher-quality random numbers (see the following section for details). Table 16-5 documents the most frequently used functions exposed by the `random` module.

Table 16-5. Useful functions supplied by the `random` module

`choice`	`choice(`*`seq`*`)` Returns a random item from nonempty sequence *`seq`*.
`choices`	`choices(`*`seq`*`, `*`weights`*`=`**`None`**`, *, cum_weights=`**`None`**`, k=1)` Returns k elements from nonempty sequence *`seq`*, with replacement. By default, elements are chosen with equal probability. If the optional *`weights`*, or the named argument `cum_weights`, is passed (as a list of `float`s or `int`s), then the respective choices are weighted by that amount during choosing. The `cum_weights` argument accepts a list of `float`s or `int`s as would be returned by `itertools.accumulate(`*`weights`*`)`; e.g., if *`weights`* for a *`seq`* containing three items were `[1, 2, 1]`, then the corresponding `cum_weights` would be `[1, 3, 4]`. (Only one of *`weights`* or `cum_weights` may be specified, and must be the same length as *`seq`*. If used, `cum_weights` and `k` must be given as named arguments.)
`getrand bits`	`getrandbits(`*`k`*`)` Returns an `int >= 0` with *k* random bits, like `randrange(2 ** `*`k`*`)` (but faster, and with no problems for large *k*).
`getstate`	`getstate()` Returns a hashable and pickleable object *S* representing the current state of the generator. You can later pass *S* to the function `setstate` to restore the generator's state.
`jumpahead`	`jumpahead(`*`n`*`)` Advances the generator state as if *n* random numbers had been generated. This is faster than generating and ignoring *n* random numbers.
`randbytes`	`randbytes(`*`k`*`)` **3.9+** Generates *k* random bytes. To generate bytes for secure or cryptographic applications, use `secrets.randbits(`*`k`*` * 8)`, then unpack the `int` it returns into *k* bytes, using `int.to_bytes(`*`k`*`, 'big')`.

`randint`	`randint(`*`start`*`, `*`stop`*`)` Returns a random `int` *`i`* from a uniform distribution such that *`start`* <= *`i`* <= *`stop`*. Both endpoints are included: this is quite unnatural in Python, so you would normally prefer `randrange`.
`random`	`random()` Returns a random `float` *`r`* from a uniform distribution, `0 <=` *`r`* `< 1`.
`randrange`	`randrange([`*`start`*`,]`*`stop`*`[,`*`step`*`])` Like `choice(range(`*`start`*`, `*`stop`*`, `*`step`*`))`, but much faster.
`sample`	`sample(`*`seq`*`, `*`k`*`)` Returns a new list whose *k* items are unique items randomly drawn from *`seq`*. The list is in random order, so that any slice of it is an equally valid random sample. *`seq`* may contain duplicate items. In this case, each occurrence of an item is a candidate for selection in the sample, and the sample may also contain such duplicates.
`seed`	`seed(`*`x`*`=`**`None`**`)` Initializes the generator state. *x* can be any `int`, `float`, `str`, `bytes`, or `bytearray`. When *x* is **None**, and when the module `random` is first loaded, `seed` uses the current system time (or some platform-specific source of randomness, if any) to get a seed. *x* is normally an `int` up to 2^{256}, a `float`, or a `str`, `bytes`, or `bytearray` up to 32 bytes in size.[a] Larger *x* values are accepted, but may produce the same generator state as smaller ones. `seed` is useful in simulation or modeling for repeatable runs, or to write tests that require a reproducible sequence of random values.
`setstate`	`setstate(`*`S`*`)` Restores the generator state. *`S`* must be the result of a previous call to `getstate` (such a call may have occurred in another program, or in a previous run of this program, as long as object *`S`* has correctly been transmitted, or saved and restored).
`shuffle`	`shuffle(`*`seq`*`)` Shuffles, in place, mutable sequence *`seq`*.
`uniform`	`uniform(`*`a`*`, `*`b`*`)` Returns a random floating-point number *`r`* from a uniform distribution such that *a* <= *`r`* < *b*.

[a] As defined in the Python language specification. Specific Python implementations may support larger seed values for generating unique random number sequences.

The `random` module also supplies several other functions that generate pseudorandom floating-point numbers from other probability distributions (Beta, Gamma, exponential, Gauss, Pareto, etc.) by internally calling `random.random` as their source of randomness. See the online docs for details.

Crypto-Quality Random Numbers: The secrets Module

Pseudorandom numbers provided by the `random` module, while sufficient for simulation and modeling, are not of cryptographic quality. To get random numbers and sequences for use in security and cryptography applications, use the functions defined in the `secrets` module. These functions use the `random.SystemRandom` class, which in turn calls `os.urandom`. `os.urandom` returns random bytes, read from physical sources of random bits such as */dev/urandom* on older Linux releases, or the **getrandom()** syscall on Linux 3.17 and above. On Windows, os.urandom uses cryptographical-strength sources such as the CryptGenRandom API. If no suitable source exists on the current system, os.urandom raises NotImplementedError.

> **secrets Functions Cannot Be Run with a Known Seed**
>
> Unlike the random module, which includes a seed function to support generation of repeatable sequences of random values, the secrets module has no such capability. To write tests dependent on specific sequences of random values generated by the secrets module functions, developers must emulate those functions with their own mock versions.

The secrets module supplies the functions listed in Table 16-6.

Table 16-6. Functions of the secrets module

choice	choice(*seq*) Returns a randomly selected item from nonempty sequence *seq*.
randbelow	randbelow(*n*) Returns a random int *x* in the range 0 <= *x* < *n*.
randbits	randbits(*k*) Returns an int with *k* random bits.
token_bytes	token_bytes(*n*) Returns a bytes object of *n* random bytes. When you omit *n*, uses a default value, usually 32.
token_hex	token_hex(*n*) Returns a string of hexadecimal characters from *n* random bytes, with two characters per byte. When you omit *n*, uses a default value, usually 32.
token_url safe	token_urlsafe(*n*) Returns a string of Base64-encoded characters from *n* random bytes; the resulting string's length is approximately 1.3 times *n*. When you omit *n*, uses a default value, usually 32.

Additional recipes and best cryptographic practices are provided in Python's online documentation.

Alternative sources of physically random numbers are available online, e.g. from Fourmilab.

The fractions Module

The fractions module supplies a rational number class, Fraction, whose instances you can construct from a pair of integers, another rational number, or a str. Fraction class instances have read-only attributes numerator and denominator.

You can pass a pair of (optionally signed) `int`s as the *numerator* and *denominator*. A denominator of `0` raises `ZeroDivisionError`. A string can be of the form `'3.14'`, or can include an optionally signed numerator, a slash (`/`) , and a denominator, such as `'-22/7'`.

Fraction Reduces to Lowest Terms

`Fraction` reduces the fraction to the lowest terms—for example, `f = Fraction(226, 452)` builds an instance `f` equal to one built by `Fraction(1, 2)`. The specific numerator and denominator originally passed to `Fraction` are not recoverable from the resulting instance.

`Fraction` also supports construction from `decimal.Decimal` instances, and from `float`s (the latter may not provide the results you expect, given `float`s' bounded precision). Here are some examples of using `Fraction` with various inputs.

```
>>> from fractions import Fraction
>>> from decimal import Decimal
>>> Fraction(1,10)

Fraction(1, 10)

>>> Fraction(Decimal('0.1'))

Fraction(1, 10)

>>> Fraction('0.1')

Fraction(1, 10)

>>> Fraction('1/10')

Fraction(1, 10)

>>> Fraction(0.1)

Fraction(3602879701896397, 36028797018963968)

>>> Fraction(-1, 10)

Fraction(-1, 10)

>>> Fraction(-1,-10)

Fraction(1, 10)
```

The `Fraction` class supplies methods including `limit_denominator`, which allows you to create a rational approximation of a `float`—for example, `Fraction(0.0999).limit_denominator(10)` returns `Fraction(1, 10)`. `Fraction` instances are immutable and can be keys in `dict`s or members of `set`s, as well as being usable in arithmetic operations with other numbers. See the online docs for complete coverage.

The `fractions` module also supplies a function `gcd` that's just like `math.gcd`, covered in Table 16-1.

The decimal Module

A Python `float` is a binary floating-point number, normally according to the standard known as IEEE 754 implemented in hardware in modern computers. An excellent, concise, practical introduction to floating-point arithmetic and its issues can be found in David Goldberg's paper "What Every Computer Scientist Should Know About Floating-Point Arithmetic". A Python-focused essay on the same issues is part of the tutorial in the Python docs; another excellent summary (not focused on Python), Bruce Bush's "The Perils of Floating Point," is also available online.

Often, particularly for money-related computations, you may prefer to use *decimal* floating-point numbers. Python supplies an implementation of the standard known as IEEE 854,[1] for base 10, in the standard library module `decimal`. The module has excellent documentation: there, you can find complete reference material, pointers to the applicable standards, a tutorial, and advocacy for `decimal`. Here, we cover only a small subset of `decimal`'s functionality, the most frequently used parts of the module.

The `decimal` module supplies a `Decimal` class (whose immutable instances are decimal numbers), exception classes, and classes and functions to deal with the *arithmetic context*, which specifies such things as precision, rounding, and which computational anomalies (such as division by zero, overflow, underflow, and so on) raise exceptions when they occur. In the default context, precision is 28 decimal digits, rounding is "half-even" (round results to the closest representable decimal number; when a result is exactly halfway between two such numbers, round to the one whose last digit is even), and the anomalies that raise exceptions are invalid operation, division by zero, and overflow.

To build a decimal number, call `Decimal` with one argument: an `int`, `float`, `str`, or `tuple`. If you start with a `float`, Python converts it losslessly to the exact decimal equivalent (which may require 53 digits or more of precision):

```
>>> from decimal import Decimal
>>> df = Decimal(0.1)
>>> df
Decimal('0.1000000000000000055511151231257827021181583404541015625')
```

If this is not the behavior you want, you can pass the `float` as a `str`; for example:

```
>>> ds = Decimal(str(0.1))  # or, more directly, Decimal('0.1')
>>> ds
Decimal('0.1')
```

1 Superseded, technically, by the more recent, very similar standard 754-2008, but practically still useful!

You can easily write a factory function for ease of interactive experimentation with decimal:

```
def dfs(x):
    return Decimal(str(x))
```

Now dfs(0.1) is just the same thing as Decimal(str(0.1)), or Decimal('0.1'), but more concise and handier to write.

Alternatively, you may use the quantize method of Decimal to construct a new decimal by rounding a float to the number of significant digits you specify:

```
>>> dq = Decimal(0.1).quantize(Decimal('.00'))
>>> dq

Decimal('0.10')
```

If you start with a tuple, you need to provide three arguments: the sign (0 for positive, 1 for negative), a tuple of digits, and the integer exponent:

```
>>> pidigits = (3, 1, 4, 1, 5)
>>> Decimal((1, pidigits, -4))

Decimal('-3.1415')
```

Once you have instances of Decimal, you can compare them, including comparison with floats (use math.isclose for this); pickle and unpickle them; and use them as keys in dictionaries and as members of sets. You may also perform arithmetic among them, and with integers, but not with floats (to avoid unexpected loss of precision in the results), as shown here:

```
>>> import math
>>> from decimal import Decimal
>>> a = 1.1
>>> d = Decimal('1.1')
>>> a == d

False

>>> math.isclose(a, d)

True

>>> a + d

Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: unsupported operand type(s) for +: 'float' and
'decimal.Decimal'

>>> d + Decimal(a) # new decimal constructed from 'a'

Decimal('2.200000000000000088817841970')

>>> d + Decimal(str(a)) # convert 'a' to decimal with str(a)

Decimal('2.20')
```

The online docs include useful recipes for monetary formatting, some trigonometric functions, and a list of FAQs.

Array Processing

You can represent what most languages call arrays, or vectors, with lists (covered in "Lists" on page 47), as well as with the `array` standard library module (covered in the following subsection). You can manipulate arrays with loops, indexing and slicing, list comprehensions, iterators, generators, and genexps (all covered in Chapter 3); built-ins such as `map`, `reduce`, and `filter` (all covered in "Built-in Functions" on page 251); and standard library modules such as `itertools` (covered in "The itertools Module" on page 275). If you only need a lightweight, one-dimensional array of instances of a simple type, stick with `array`. However, to process large arrays of numbers, such functions may be slower and less convenient than third-party extensions such as NumPy and SciPy (covered in "Extensions for Numeric Array Computation" on page 504). When you're doing data analysis and modeling, Pandas, which is built on top of NumPy (but not discussed in this book), might be most suitable.

The array Module

The `array` module supplies a type, also called `array`, whose instances are mutable sequences, like lists. An `array` *a* is a one-dimensional sequence whose items can be only characters, or only numbers of one specific numeric type, fixed when you create *a*. The constructor for `array` is:

`array` **`class`** `array(`*`typecode, init`*`='', /)`

Creates and returns an `array` object *a* with the given *`typecode`*. *`init`* can be a string (a bytestring, except for *`typecode`* `'u'`) whose length is a multiple of `itemsize`: the string's bytes, interpreted as machine values, directly initialize *a*'s items. Alternatively, *`init`* can be an iterable (of characters when *`typecode`* is `'u'`, otherwise of numbers): each item of the iterable initializes one item of *a*.

`array.array`'s advantage is that, compared to a list, it can save memory when you need to hold a sequence of objects all of the same (numeric or character) type. An `array` object *a* has a one-character, read-only attribute *`a`*`.typecode`, set on creation, which specifies the type of *a*'s items. Table 16-7 shows the possible `typecode` values for `array`.

Table 16-7. Type codes for the `array` module

typecode	C type	Python type	Minimum size
`'b'`	`char`	`int`	1 byte
`'B'`	`unsigned char`	`int`	1 byte
`'u'`	`unicode char`	`str (length 1)`	See note

typecode	C type	Python type	Minimum size
'h'	short	int	2 bytes
'H'	unsigned short	int	2 bytes
'i'	int	int	2 bytes
'I'	unsigned int	int	2 bytes
'l'	long	int	4 bytes
'L'	unsigned long	int	4 bytes
'q'	long long	int	8 bytes
'Q'	unsigned long long	int	8 bytes
'f'	float	float	4 bytes
'd'	double	float	8 bytes

Minimum Size of typecode 'u'

`'u'` has an item size of 2 on a few platforms (notably, Windows) and 4 on just about every other platform. You can check the build type of a Python interpreter by using `array.array('u').itemsize`.

The size, in bytes, of each item of an `array` *a* may be larger than the minimum, depending on the machine's architecture, and is available as the read-only attribute *a*`.itemsize`.

Array objects expose all methods and operations of mutable sequences (as covered in "Sequence Operations" on page 62), except `sort`. Concatenation with `+` or `+=`, and slice assignment, require both operands to be arrays with the same `typecode`; in contrast, the argument to *a*`.extend` can be any iterable with items acceptable to *a*. In addition to the methods of mutable sequences (`append`, `extend`, `insert`, `pop`, etc.), an `array` object *a* exposes the methods and properties listed in Table 16-8.

Table 16-8. Methods and properties of an `array` *object a*

`buffer_info`	*a*`.buffer_info()` Returns a two-item tuple (*`address, array_length`*), where *`array_length`* is the number of items that you can store in *a*. The size of *a* in bytes is *a*`.buffer_info()[1] *` *a*`.itemsize`.
`byteswap`	*a*`.byteswap()` Swaps the byte order of each item of *a*.
`frombytes`	*a*`.frombytes(`*s*`)` Appends to *a* the bytes, interpreted as machine values, of `bytes` *s*. `len(`*s*`)` must be an exact multiple of *a*`.itemsize`.

`fromfile`	*a*.fromfile(*f*, *n*) Reads *n* items, taken as machine values, from file object *f* and appends the items to *a*. *f* should be open for reading in binary mode—typically, mode `'rb'` (see "Creating a File Object with open" on page 323). When fewer than *n* items are available in *f*, `fromfile` raises `EOFError` after appending the items that are available (so, be sure to catch this in a **`try`**/**`except`**, if that's OK in your app!).
`fromlist`	*a*.fromlist(*L*) Appends to *a* all items of list *L*.
`fromunicode`	*a*.fromunicode(*s*) Appends to *a* all characters from string *s*. *a* must have typecode `'u'`; otherwise, Python raises `ValueError`.
`itemsize`	*a*.itemsize Property that returns the size, in bytes, of each item in *a*.
`tobytes`	*a*.tobytes() `tobytes` returns the bytes representation of the items in a. For any *a*, `len(`*a*`.tobytes())` == `len(`*a*`)*`*a*`.itemsize`. *f*`.write(`*a*`.tobytes())` is the same as *a*`.tofile(`*f*`)`.
`tofile`	*a*.tofile(*f*) Writes all items of *a*, taken as machine values, to file object *f*. Note that *f* should be open for writing in binary mode—for example, with mode `'wb'`.
`tolist`	*a*.tolist() Creates and returns a list object with the same items as *a*, like `list(`*a*`)`.
`tounicode`	*a*.tounicode() Creates and returns a string with the same items as *a*, like `''.join(`*a*`)`. *a* must have typecode `'u'`; otherwise, Python raises `ValueError`.
`typecode`	*a*.typecode Property that returns the `typecode` used to create a.

Extensions for Numeric Array Computation

As you've seen, Python has great built-in support for numeric processing. The third-party library SciPy, and many, *many* other packages, such as NumPy, Matplotlib, SymPy, Numba, Pandas, PyTorch, CuPy, and TensorFlow, provide even more tools. We introduce NumPy here, then provide a brief description of SciPy and some other packages, with pointers to their documentation.

NumPy

If you need a lightweight, one-dimensional array of numbers, the standard library's `array` module may suffice. If your work involves scientific computing, image processing, multidimensional arrays, linear algebra, or other applications involving large amounts of data, the popular third-party NumPy package meets your needs.

Extensive documentation is available online; a free PDF of Travis Oliphant's *Guide to NumPy* is also available.[2]

NumPy or numpy?

The docs variously refer to the package as NumPy or Numpy; however, in coding, the package is called `numpy`, and you usually import it with **`import`** `numpy` **`as`** `np`. This section follows those conventions.

NumPy provides the class `ndarray`, which you can subclass to add functionality for your particular needs. An `ndarray` object has *`n`* dimensions of homogeneous items (items can include containers of heterogeneous types). Each `ndarray` object *`a`* has a certain number of dimensions (aka *axes*), known as its *rank*. A *scalar* (i.e., a single number) has rank `0`, a *vector* has rank `1`, a *matrix* has rank `2`, and so forth. An `ndarray` object also has a *shape*, which can be accessed as property `shape`. For example, for a matrix *`m`* with 2 columns and 3 rows, *`m`*`.shape` is `(3,2)`.

NumPy supports a wider range of numeric types (instances of `dtype`) than Python; the default numerical types are `bool_` (1 byte), `int_` (either `int64` or `int32`, depending on your platform), `float_` (short for `float64`), and `complex_` (short for `complex128`).

Creating a NumPy array

There are several ways to create an array in NumPy. Among the most common are:

- With the factory function `np.array`, from a sequence (often a nested one), with *type inference* or by explicitly specifying *`dtype`*
- With factory functions `np.zeros`, `np.ones`, or `np.empty`, which default to *`dtype`* `float64`
- With factory function `np.indices`, which defaults to *`dtype`* `int64`
- With factory functions `np.random.uniform`, `np.random.normal`, `np.random.binomial`, etc., which default to *`dtype`* `float64`
- With factory function `np.arange` (with the usual *`start`*, *`stop`*, *`stride`*), or with factory function `np.linspace` (with *`start`*, *`stop`*, *`quantity`*) for better floating-point behavior
- By reading data from files with other `np` functions (e.g., CSV with `np.genfromtxt`)

2 Python and the NumPy project have worked closely together for many years, with Python introducing language features specifically for NumPy (such as the `@` operator and extended slicing) even though such novel language features are not (yet?) used anywhere in the Python standard library.

Here are some examples of creating an array using the various techniques just described:

```
>>> import numpy as np
>>> np.array([1, 2, 3, 4])  # from a Python list
array([1, 2, 3, 4])
>>> np.array(5, 6, 7)  # a common error: passing items separately (they
                       # must be passed as a sequence, e.g. a list)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: array() takes from 1 to 2 positional arguments, 3 were given
>>> s = 'alph', 'abet'  # a tuple of two strings
>>> np.array(s)
array(['alph', 'abet'], dtype='<U4')
>>> t = [(1,2), (3,4), (0,1)]  # a list of tuples
>>> np.array(t, dtype='float64')  # explicit type designation
array([[1., 2.],
       [3., 4.],
       [0., 1.]])
>>> x = np.array(1.2, dtype=np.float16)  # a scalar
>>> x.shape
()
>>> x.max()
1.2
>>> np.zeros(3)  # shape defaults to a vector
array([0., 0., 0.])
>>> np.ones((2,2))  # with shape specified
array([[1., 1.],
[1., 1.]])
>>> np.empty(9)  # arbitrary float64s
array([ 6.17779239e-31, -1.23555848e-30,  3.08889620e-31,
       -1.23555848e-30,  2.68733969e-30, -8.34001973e-31,
            3.08889620e-31, -8.34001973e-31,  4.78778910e-31])
>>> np.indices((3,3))
array([[[0, 0, 0],
        [1, 1, 1],
        [2, 2, 2]],

       [[0, 1, 2],
        [0, 1, 2],
        [0, 1, 2]]])
```

```
>>> np.arange(0, 10, 2)  # upper bound excluded
array([0, 2, 4, 6, 8])
>>> np.linspace(0, 1, 5)  # default: endpoint included
array([0.  , 0.25, 0.5 , 0.75, 1.  ])
>>> np.linspace(0, 1, 5, endpoint=False)  # endpoint not included
array([0. , 0.2, 0.4, 0.6, 0.8])
>>> np.genfromtxt(io.BytesIO(b'1 2 3\n4 5 6'))  # using a pseudo-file
array([[1., 2., 3.],
       [4., 5., 6.]])
>>> with open('x.csv', 'wb') as f:
...     f.write(b'2,4,6\n1,3,5')
...
11
>>> np.genfromtxt('x.csv', delimiter=',')  # using an actual CSV file
array([[2., 4., 6.],
       [1., 3., 5.]])
```

Shape, indexing, and slicing

Each `ndarray` object *a* has an attribute *a*`.shape`, which is a tuple of `int`s. `len(`*a*`.shape)` is *a*'s *rank*; for example, a one-dimensional array of numbers (also known as a *vector*) has rank `1`, and *a*`.shape` has just one item. More generally, each item of *a*`.shape` is the length of the corresponding dimension of *a*. *a*'s number of elements, known as its *size*, is the product of all items of *a*`.shape` (also available as property *a*`.size`). Each dimension of *a* is also known as an *axis*. Axis indices are from `0` and up, as usual in Python. Negative axis indices are allowed and count from the right, so `-1` is the last (rightmost) axis.

Each array *a* (except a scalar, meaning an array of rank `0`) is a Python sequence. Each item *a*`[`*i*`]` of *a* is a subarray of *a*, meaning it is an array with a rank one less than *a*'s: *a*`[`*i*`].shape == `*a*`.shape[1:]`. For example, if *a* is a two-dimensional matrix (*a* is of rank `2`), *a*`[`*i*`]`, for any valid index *i*, is a one-dimensional subarray of *a* that corresponds to one row of the matrix. When *a*'s rank is `1` or `0`, *a*'s items are *a*'s elements (just one element, for rank `0` arrays). Since *a* is a sequence, you can index *a* with normal indexing syntax to access or change *a*'s items. Note that *a*'s items are *a*'s subarrays; only for an array of rank `1` or `0` are the array's *items* the same thing as the array's *elements*.

As with any other sequence, you can also *slice* *a*. After *b* `=` *a*`[`*i*`:`*j*`]`, *b* has the same rank as *a*, and *b*`.shape` equals *a*`.shape` except that *b*`.shape[0]` is the length of the slice *a*`[`*i*`:`*j*`]`, (i.e., when *a*`.shape[0] >` *j* `>=` *i* `>= 0`, the length of the slice is *j* `-` *i*, as described in "Slicing a sequence" on page 64).

Once you have an array *a*, you can call *a*.reshape (or, equivalently, np.reshape with *a* as the first argument). The resulting shape must match *a*.size: when *a*.size is 12, you can call *a*.reshape(3, 4) or *a*.reshape(2, 6), but *a*.reshape(2, 5) raises ValueError. Note that reshape does not work in place: you must explicitly bind or rebind the array, for example, *a* = *a*.reshape(*i*, *j*) or *b* = *a*.reshape(*i*, *j*).

You can also loop on (nonscalar) *a* with **for**, just as you can with any other sequence. For example, this:

```
for x in a:
    process(x)
```

means the same thing as:

```
for _ in range(len(a)):
    x = a[_]
    process(x)
```

In these examples, each item *x* of *a* in the **for** loop is a subarray of *a*. For example, if *a* is a two-dimensional matrix, each *x* in either of these loops is a one-dimensional subarray of *a* that corresponds to a row of the matrix.

You can also index or slice *a* by a tuple. For example, when *a*'s rank is >= 2, you can write *a*[*i*][*j*] as *a*[*i*, *j*], for any valid *i* and *j*, for rebinding as well as for access; tuple indexing is faster and more convenient. *Do not put parentheses* inside the brackets to indicate that you are indexing *a* by a tuple: just write the indices one after the other, separated by commas. *a*[*i*, *j*] means exactly the same thing as *a*[(*i*, *j*)], but the form without parentheses is more readable.

An indexing is a slicing in which one or more of the tuple's items are slices, or (at most once per slicing) the special form ... (the Python built-in Ellipsis). ... expands into as many all-axis slices (:) as needed to "fill" the rank of the array you're slicing. For example, *a*[1,...,2] is like *a*[1,:,:,2] when *a*'s rank is 4, but like *a*[1,:,:,:,:,2] when *a*'s rank is 6.

The following snippets show looping, indexing, and slicing:

```
>>> a = np.arange(8)
>>> a

array([0, 1, 2, 3, 4, 5, 6, 7])

>>> a = a.reshape(2,4)
>>> a

array([[0, 1, 2, 3],
       [4, 5, 6, 7]])

>>> print(a[1,2])

6

>>> a[:,:2]
```

```
array([[0, 1],
       [4, 5]])
>>> for row in a:
...     print(row)
...
[0 1 2 3]
[4 5 6 7]
>>> for row in a:
...     for col in row[:2]:  # first two items in each row
...         print(col)
...
0
1
4
5
```

Matrix operations in NumPy

As mentioned in "The operator Module" on page 493, NumPy implements the operator `@` for matrix multiplication of arrays. `a1 @ a2` is like `np.matmul(a1, a2)`. When both matrices are two-dimensional, they're treated as conventional matrices. When one argument is a vector, you conceptually promote it to a two-dimensional array, as if by temporarily appending or prepending a `1`, as needed, to its shape. Do not use `@` with a scalar; use `*` instead. Matrices also allow addition (using `+`) with a scalar, as well as with vectors and other matrices of compatible shapes. Dot product is also available for matrices, using `np.dot(a1, a2)`. A few simple examples of these operators follow:

```
>>> a = np.arange(6).reshape(2,3)  # a 2D matrix
>>> b = np.arange(3)               # a vector
>>>
>>> a
array([[0, 1, 2],
       [3, 4, 5]])
>>> a + 1    # adding a scalar
array([[1, 2, 3],
       [4, 5, 6]])
>>> a + b    # adding a vector
array([[0, 2, 4],
       [3, 5, 7]])
>>> a * 2    # multiplying by a scalar
array([[ 0,  2,  4],
       [ 6,  8, 10]])
>>> a * b    # multiplying by a vector
```

Numeric Processing

```
array([[ 0,  1,  4],
       [ 0,  4, 10]])
>>> a @ b     # matrix-multiplying by a vector
array([ 5, 14])
>>> c = (a*2).reshape(3,2)  # using scalar multiplication to create
>>> c
array([[ 0,  2],
       [ 4,  6],
       [ 8, 10]])
>>> a @ c     # matrix-multiplying two 2D matrices
array([[20, 26],
       [56, 80]])
```

NumPy is rich and powerful enough to warrant whole books of its own; we have only touched on a few details. See the NumPy documentation for extensive coverage of its many, many features.

SciPy

Whereas NumPy contains classes and functions for handling arrays, the SciPy library supports more advanced numeric computation. For example, while NumPy provides a few linear algebra methods, SciPy provides advanced decomposition methods and supports more advanced functions, such as allowing a second matrix argument for solving generalized eigenvalue problems. In general, when you are doing advanced numeric computation, it's a good idea to install both SciPy and NumPy.

SciPy.org also hosts docs for a number of other packages, which are integrated with SciPy and NumPy, including Matplotlib, which provides 2D plotting support; SymPy, which supports symbolic mathematics; Jupyter Notebook, a powerful interactive console shell and web application kernel; and Pandas, which supports data analysis and modeling. You may also want to take a look at `mpmath`, for arbitrary precision, and `sagemath`, for even richer functionality.

Additional numeric packages

The Python community has produced many more packages in the field of numeric processing. A few of them are:

Anaconda
: A consolidated environment that simplifies the installation of Pandas, NumPy, and many related numerical processing, analytical, and visualization packages, and provides package management via its own `conda` package installer.

`gmpy2`
: A module[3] that supports the GMP/MPIR, MPFR, and MPC libraries, to extend and accelerate Python's abilities for multiple-precision arithmetic.

Numba
: A just-in-time compiler to convert Numba-decorated Python functions and NumPy code to LLVM. Numba-compiled numerical algorithms in Python can approach the speeds of C or FORTRAN.

PyTorch
: An open source machine learning framework.

TensorFlow
: A comprehensive machine learning platform that operates at large scale and in mixed environments, using dataflow graphs to represent computation, shared state, and state manipulation operations. TensorFlow supports processing across multiple machines in a cluster, and within-machine across multicore CPUs, GPUs, and custom-designed ASICs. TensorFlow's main API uses Python.

3 Originally derived from the work of one of this book's authors.

17
Testing, Debugging, and Optimizing

You're not finished with a programming task when you're done writing the code; you're finished only when the code runs correctly and with acceptable performance. *Testing* means verifying that code runs correctly by automatically exercising the code under known conditions and checking that the results are as expected. *Debugging* means discovering causes of incorrect behavior and repairing them (repair is often easy, once you figure out the causes).

Optimizing is often used as an umbrella term for activities meant to ensure acceptable performance. Optimizing breaks down into *benchmarking* (measuring performance for given tasks to check that it's within acceptable bounds), *profiling* (*instrumenting* the program with extra code to identify performance bottlenecks), and actual optimizing (removing bottlenecks to improve program performance). Clearly, you can't remove performance bottlenecks until you've found out where they are (via profiling), which in turn requires knowing that there *are* performance problems (via benchmarking).

This chapter covers these subjects in the natural order in which they occur in development: testing first and foremost, debugging next, and optimizing last. Most programmers' enthusiasm focuses on optimization: testing and debugging are often (wrongly!) perceived as being chores, while optimization is seen as being fun. Were you to read only one section of the chapter, we might suggest that section be "Developing a Fast-Enough Python Application" on page 542, which summarizes the Pythonic approach to optimization—close to Jackson's classic "Rules of Optimization: Rule 1. Don't do it. Rule 2 (for experts only). Don't do it *yet*."

All of these tasks are important; discussion of each could fill at least a book by itself. This chapter cannot even come close to exploring every related technique; rather, it focuses on Python-specific approaches and tools. Often, for best results, you should approach the issue from the higher-level viewpoint of *system analysis and design*, rather than focusing only on implementation (in Python and/or any other mix of programming languages). Start by studying a good general book on the subject, such as *Systems Analysis and Design* by Alan Dennis, Barbara Wixom, and Roberta Roth (Wiley).

Testing

In this chapter, we distinguish between two different kinds of testing: *unit testing* and *system testing*. Testing is a rich, important field: many more distinctions could be drawn, but we focus on the issues that most matter to most software developers. Many developers are reluctant to spend time on testing, seeing it as time stolen from "real" development, but this is shortsighted: problems in code are easier to fix the earlier you find out about them. An extra hour spent developing tests will amply pay for itself as you find defects early, saving you many hours of debugging that would otherwise have been needed in later phases of the software development cycle.[1]

Unit Testing and System Testing

Unit testing means writing and running tests to exercise a single module, or an even smaller unit, such as a class or function. *System testing* (also known as *functional*, *integration*, or *end-to-end* testing) involves running an entire program with known inputs. Some classic books on testing also draw the distinction between *white-box testing*, done with knowledge of a program's internals, and *black-box testing*, done without such knowledge. This classic viewpoint parallels, but does not exactly duplicate, the modern one of unit versus system testing.

Unit and system testing serve different goals. Unit testing proceeds apace with development; you can and should test each unit as you're developing it. One relatively modern approach (first proposed in 1971 in Gerald Weinberg's immortal classic *The Psychology of Computer Programming* [Dorset House]) is known as *test-driven development* (TDD): for each feature that your program must have, you first write unit tests, and only then do you proceed to write code that implements the feature and makes the tests pass. TDD may seem upside down, but it has advantages; for example, it ensures that you won't omit unit tests for some feature. This approach is helpful because it urges you to focus first on exactly *what tasks* a certain function, class, or method should accomplish, dealing only afterward with *how* to implement that function, class, or method. An innovation along the lines of TDD is *behavior-driven development* (BDD).

1 This issue is related to "technical debt" and other topics covered in the "'Good enough' is good enough" tech talk by one of this book's authors (that author's favorite tech talk out of the many he delivered!), excellently summarized and discussed by Martin Michlmayr on LWN.net.

To test a unit—which may depend on other units not yet fully developed—you often have to write *stubs*, also known as *mocks*:[2] fake implementations of various units' interfaces giving known, correct responses in cases needed to test other units. The `mock` module (part of Python's standard library, in the package `unittest`) helps you implement such stubs.

System testing comes later, since it requires the system to exist, with at least some subset of system functionality believed (based on unit testing) to be working. System testing offers a soundness check: each module in the program works properly (passes unit tests), but does the *whole* program work? If each unit is OK but the system is not, there's a problem in the integration between units—the way the units cooperate. For this reason, system testing is also known as integration testing.

System testing is similar to running the system in production use, except that you fix inputs in advance so that any problems you may find are easy to reproduce. The cost of failures in system testing is lower than in production use, since outputs from system testing are not used to make decisions, serve customers, control external systems, and so on. Rather, outputs from system testing are systematically compared with the outputs that the system *should* produce given the known inputs. The purpose is to find, in cheap and reproducible ways, discrepancies between what the program *should* do and what the program actually *does*.

Failures discovered by system testing (just like system failures in production use) may reveal defects in unit tests, as well as defects in the code. Unit testing may have been insufficient: a module's unit tests may have failed to exercise all the needed functionality of the module. In that case, the unit tests need to be beefed up. Do that *before* you change your code to fix the problem, then run the newly enhanced unit tests to confirm that they now show the problem. Then fix the problem, and run the unit tests again to confirm that they no longer show it. Finally, rerun the system tests to confirm that the problem has indeed gone away.

Bug-Fixing Best Practice

This best practice is a specific application of test-driven design that we recommend without reservation: never fix a bug before having added unit tests that would have revealed the bug. This provides an excellent, cheap insurance against software regression bugs.

Often, failures in system testing reveal communication problems within the development team:[3] a module correctly implements a certain functionality, but another

2 The language used in this area is confused and confusing: terms like *dummies*, *fakes*, *spies*, *mocks*, *stubs*, and *test doubles* are utilized by different people to mean slightly different things. For an authoritative approach to terminology and concepts (though not the exact one we use), see the essay "Mocks Aren't Stubs" by Martin Fowler.

3 That's partly because the structure of the system tends to mirror the structure of the organization, per Conway's law.

module expects different functionality. This kind of problem (an integration problem in the strict sense) is hard to pinpoint in unit testing. In good development practice, unit tests must run often, so it is crucial that they run fast. It's therefore essential, in the unit testing phase, that each unit can assume other units are working correctly and as expected.

Unit tests run in reasonably late stages of development can reveal integration problems if the system architecture is hierarchical, a common and reasonable organization. In such an architecture, low-level modules depend on no others (except library modules, which you can typically assume to be correct), so the unit tests of such low-level modules, if complete, suffice to provide confidence of correctness. High-level modules depend on low-level ones, and thus also depend on correct understanding about what functionality each module expects and supplies. Running complete unit tests on high-level modules (using true low-level modules, not stubs) exercises interfaces between modules, as well as the high-level modules' own code.

Unit tests for high-level modules are thus run in two ways. You run the tests with stubs for the low levels during the early stages of development, when the low-level modules are not yet ready or, later, when you only need to check the correctness of the high levels. During later stages of development, you also regularly run the high-level modules' unit tests using the true low-level modules. In this way, you check the correctness of the whole subsystem, from the high levels downward. Even in this favorable case, you *still* need to run system tests to ensure that you have checked that all of the system's functionality is exercised and you have neglected no interfaces between modules.

System testing is similar to running the program in normal ways. You need special support only to ensure supply of known inputs and capture of resulting outputs for comparison with expected outputs. This is easy for programs that perform I/O on files, and hard for programs whose I/O relies on a GUI, network, or other communication with external entities. To simulate such external entities and make them predictable and entirely observable, you generally need platform-dependent infrastructure. Another useful piece of supporting infrastructure for system testing is a *testing framework* to automate the running of system tests, including logging of successes and failures. Such a framework can also help testers prepare sets of known inputs and corresponding expected outputs.

Both free and commercial programs for these purposes exist, and usually do not depend on which programming languages are used in the system under test. System testing is a close relative of what was classically known as black-box testing: testing that is independent from the implementation of the system under test (and thus, in particular, independent from the programming languages used for implementation). Instead, testing frameworks usually depend on the operating system platform on which they run, since the tasks they perform are platform dependent. These include:

- Running programs with given inputs
- Capturing their outputs

- Simulating/capturing GUI, network, and other interprocess communication I/O

Since frameworks for system testing depend on the platform, not on programming languages, we do not cover them further in this book. For a thorough list of Python testing tools, see the Python wiki.

The doctest Module

The `doctest` module exists to let you create good examples in your code's docstrings, checking that the examples do in fact produce the results that your docstrings show for them. `doctest` recognizes such examples by looking within the docstring for the interactive Python prompt `>>>`, followed on the same line by a Python statement, and the statement's expected output on the next line(s).

As you develop a module, keep the docstrings up-to-date and enrich them with examples. Each time a part of the module (e.g., a function) is ready, or partially ready, make it a habit to add examples to its docstring. Import the module into an interactive session, and use the parts you just developed to provide examples with a mix of typical cases, limit cases, and failing cases. For this specific purpose only, use **`from`** *`module`* **`import`** `*` so that your examples don't prefix *`module.`* to each name the module supplies. Copy and paste the interactive session into the docstring in an editor, adjust any glitches, and you're almost done.

Your documentation is now enriched with examples, and readers will have an easier time following it (assuming you choose a good mix of examples, wisely seasoned with nonexample text). Make sure you have docstrings, with examples, for the module as a whole, and for each function, class, and method the module exports. You may choose to skip functions, classes, and methods whose names start with `_`, since (as their names indicate) they're private implementation details; `doctest` by default ignores them, and so should readers of your module's source code.

> **Make Your Examples Match Reality**
>
> Examples that don't match the way your code works are worse than useless. Documentation and comments are useful only if they match reality; docs and comments that "lie" can be seriously damaging.

Docstrings and comments often get out of date as code changes, and thus become misinformation, hampering, rather than helping, any reader of the source. It's better to have no comments and docstrings at all, poor as such a choice would be, than to have ones that lie. `doctest` can help you by running and checking the examples in your docstrings. A failing `doctest` run should prompt you to review the docstring that contains the failing example, thus reminding you to keep the whole docstring updated.

At the end of your module's source, insert the following snippet:

```
if __name__ == '__main__':
    import doctest
    doctest.testmod()
```

This code calls the function `testmod` of the module `doctest` when you run your module as the main program. `testmod` examines docstrings (the module's docstring, and the docstrings of all public functions, classes, and methods thereof). In each docstring, `testmod` finds all examples (by looking for occurrences of the interpreter prompt `>>>`, possibly preceded by whitespace) and runs each example. `testmod` checks that each example's results match the output given in the docstring right after the example. In case of exceptions, `testmod` ignores the traceback, and just checks that the expected and observed error messages are equal.

When everything goes right, `testmod` terminates silently. Otherwise, it outputs detailed messages about the examples that failed, showing expected and actual output. Example 17-1 shows a typical example of `doctest` at work on a module *mod.py*.

Example 17-1. Using `doctest`

```
"""
This module supplies a single function reverse_words that reverses
a string word by word.

>>> reverse_words('four score and seven years')
'years seven and score four'
>>> reverse_words('justoneword')
'justoneword'
>>> reverse_words('')
''

You must call reverse_words with a single argument, a string:

>>> reverse_words()
Traceback (most recent call last):
    ...
TypeError: reverse_words() missing 1 required positional argument: 'astring'
>>> reverse_words('one', 'another')
Traceback (most recent call last):
    ...
TypeError: reverse_words() takes 1 positional argument but 2 were given
>>> reverse_words(1)
Traceback (most recent call last):
    ...
AttributeError: 'int' object has no attribute 'split'
>>> reverse_words('𝒰𝓃𝒾𝒸𝑜𝒹𝑒 is all right too')
'too right all is 𝒰𝓃𝒾𝒸𝑜𝒹𝑒'

As a side effect, reverse_words eliminates any redundant spacing:
```

```
>>> reverse_words('with  redundant   spacing')
'spacing redundant with'
"""

def reverse_words(astring):
    words = astring.split()
    words.reverse()
    return ' '.join(words)

if __name__ == '__main__':
    import doctest
    doctest.testmod()
```

In this module's docstring, we snipped the tracebacks from the docstring and replaced them with ellipses (`...`): this is good practice, since `doctest` ignores tracebacks, which add nothing to the explanatory value of a failing case. Apart from this snipping, the docstring is the copy and paste of an interactive session, plus some explanatory text and empty lines for readability. Save this source as *mod.py*, and then run it with **`python mod.py`**. It produces no output, meaning that all the examples work right. Try **`python mod.py -v`** to get an account of all tests it tries, and a verbose summary at the end. Finally, alter the example results in the module docstring, making them incorrect, to see the messages `doctest` provides for errant examples.

While `doctest` is not meant for general-purpose unit testing, it can be tempting to use it for that purpose. The recommended way to do unit testing in Python is with a test framework such as `unittest`, `pytest`, or `nose2` (covered in the following sections). However, unit testing with `doctest` can be easier and faster to set up, since it requires little more than copying and pasting from an interactive session. If you need to maintain a module that lacks unit tests, retrofitting such tests into the module with `doctest` is a reasonable short-term compromise, as a first step. It's better to have just `doctest`-based unit tests than not to have any unit tests at all, as might otherwise happen should you decide that setting up tests properly with `unittest` from the start would take you too long.[4]

If you do decide to use `doctest` for unit testing, don't cram extra tests into your module's docstrings. This would damage the docstrings by making them too long and hard to read. Keep in the docstrings the right amount and kind of examples, strictly for explanatory purposes, just as if unit testing were not in the picture. Instead, put the extra tests into a global variable of your module, a dictionary named `__test__`. The keys in `__test__` are strings to use as arbitrary test names; corresponding values are strings that `doctest` picks up and uses just like it uses docstrings. The values in `__test__` may also be function and class objects, in which

4 However, be sure you know exactly what you're using `doctest` for in any given case: to quote Peter Norvig, writing precisely on this subject: "Know what you're aiming for; if you aim at two targets at once you usually miss them both."

case doctest examines their docstrings for tests to run. This latter feature is a convenient way to run doctest on objects with private names, which doctest skips by default.

The doctest module also supplies two functions that return instances of the unittest.TestSuite class based on doctests, so that you can integrate such tests into testing frameworks based on unittest. Full documentation for this advanced functionality is available online.

The unittest Module

The unittest module is the Python version of a unit testing framework originally developed by Kent Beck for Smalltalk. Similar, widespread versions of the framework also exist for many other programming languages (e.g., the JUnit package for Java) and are often collectively referred to as xUnit.

To use unittest, don't put your testing code in the same source file as the tested module: rather, write a separate test module for each module to test. A popular convention is to name the test module like the module being tested, with a prefix such as 'test_', and put it in a subdirectory of the source's directory named *test*. For example, the test module for *mod.py* can be *test/test_mod.py*. A simple, consistent naming convention helps you write and maintain auxiliary scripts that find and run all unit tests for a package.

Separation between a module's source code and its unit testing code lets you refactor the module more easily, including possibly recoding some functionality in C without perturbing the unit testing code. Knowing that *test_mod.py* stays intact, whatever changes you make to *mod.py*, enhances your confidence that passing the tests in *test_mod.py* indicates that *mod.py* still works correctly after the changes.

A unit testing module defines one or more subclasses of unittest's TestCase class. Each such subclass specifies one or more test cases by defining *test case methods*: methods that are callable without arguments and whose names start with test.

The subclass usually overrides setUp, which the framework calls to prepare a new instance just before each test case, and often also tearDown, which the framework calls to clean things up right after each test case; the entire setup/teardown arrangement is known as a *test fixture*.

Each test case calls, on self, methods of the class TestCase whose names start with assert to express the conditions that the test must meet. unittest runs the test case methods within a TestCase subclass in arbitrary order, each on a new instance of the subclass, running setUp just before each test case and tearDown just after each test case.

Have setUp Use addCleanup When Needed

When `setUp` propagates an exception, `tearDown` does not execute. So, when `setUp` prepares several things needing eventual cleanup, and some preparation steps might cause uncaught exceptions, it should not rely on `tearDown` for the cleanup work. Instead, right after each preparation step succeeds, call `self.addCleanup(f, *a, **k)`, passing a cleanup callable *f* (and optionally positional and named arguments for *f*). In this case, `f(*a, **k)` does get called after the test case (after `tearDown` when `setUp` propagates no exception, but, unconditionally, even when `setUp` does propagate exceptions), so the necessary cleanup code always executes.

`unittest` provides other facilities, such as grouping test cases into test suites, per-class and per-module fixtures, test discovery, and other, even more advanced functionality. You do not need such extras unless you're building a custom unit testing framework on top of `unittest`, or, at the very least, structuring complex testing procedures for equally complex packages. In most cases, the concepts and details covered in this section are enough to perform effective and systematic unit testing. Example 17-2 shows how to use `unittest` to provide unit tests for the module *mod.py* of Example 17-1. This example, for purely demonstrative purposes, uses `unittest` to perform exactly the same tests that Example 17-1 uses as examples in docstrings using `doctest`.

Example 17-2. Using `unittest`

```
"""This module tests function reverse_words
provided by module mod.py."""
import unittest
import mod

class ModTest(unittest.TestCase):

    def testNormalCaseWorks(self):
        self.assertEqual(
            'years seven and score four',
            mod.reverse_words('four score and seven years'))

    def testSingleWordIsNoop(self):
        self.assertEqual(
            'justoneword',
            mod.reverse_words('justoneword'))

    def testEmptyWorks(self):
        self.assertEqual('', mod.reverse_words(''))

    def testRedundantSpacingGetsRemoved(self):
        self.assertEqual(
```

```
            'spacing redundant with',
            mod.reverse_words('with   redundant   spacing'))

    def testUnicodeWorks(self):
        self.assertEqual(
            'too right all is 𝒰𝓃𝒾𝒸𝑜𝒹𝑒'
            mod.reverse_words('𝒰𝓃𝒾𝒸𝑜𝒹𝑒 is all right too'))

    def testExactlyOneArgumentIsEnforced(self):
        with self.assertRaises(TypeError):
            mod.reverse_words('one', 'another')

    def testArgumentMustBeString(self):
        with self.assertRaises((AttributeError, TypeError)):
            mod.reverse_words(1)

if __name__=='__main__':
    unittest.main()
```

Running this script with **`python test/test_mod.py`** (or, equivalently, **`python -m test.test_mod`**) is just a bit more verbose than using **`python mod.py`** to run `doctest`, as in Example 17-1. *test_mod.py* outputs a `.` (dot) for each test case it runs, then a separator line of dashes, and finally a summary line, such as "Ran 7 tests in 0.110s," and a final line of "OK" if every test passed.

Each test case method makes one or more calls to methods whose names start with `assert`. Here, no method has more than one such call; in more complicated cases, however, multiple calls to assert methods from a single test case method are common.

Even in a case as simple as this, one minor aspect shows that, for unit testing, `unittest` is more powerful and flexible than `doctest`. In the method `testArgumentMustBeString`, we pass as the argument to `assertRaises` a pair of exception classes, meaning we accept either kind of exception. *test_mod.py* therefore accepts these as valid multiple implementations of *mod.py*. It accepts the implementation in Example 17-1, which tries calling the method `split` on its argument, and therefore raises `AttributeError` when called with an argument that is not a string. However, it also accepts a different hypothetical implementation, one that raises `TypeError` instead when called with an argument of the wrong type. It is possible to code such checks with `doctest`, but it would be awkward and nonobvious, while `unittest` makes it simple and natural.

This kind of flexibility is crucial for real-life unit tests, which to some extent are executable specifications for their modules. You could, pessimistically, view the need for test flexibility as meaning the interface of the code you're testing is not well-defined. However, it's best to view the interface as being defined with a useful amount of flexibility for the implementer: under circumstance *X* (argument of invalid type passed to function `reverse_words`, in this example), either of two things (raising `AttributeError` or `TypeError`) is allowed to happen.

Thus, implementations with either of the two behaviors are correct: the implementer can choose between them on the basis of such considerations as performance and clarity. Viewed in this way—as executable specifications for their modules (the modern view, and the basis of test-driven development), rather than as white-box tests strictly constrained to a specific implementation (as in some traditional taxonomies of testing)—unit tests become an even more vital component of the software development process.

The TestCase class

With `unittest`, you write test cases by extending `TestCase`, adding methods, callable without arguments, whose names start with `test`. These test case methods, in turn, call methods that your class inherits from `TestCase`, whose names start with `assert`, to indicate conditions that must hold for the tests to succeed.

The `TestCase` class also defines two methods that your class can optionally override to group actions to perform right before and after each test case method runs. This doesn't exhaust `TestCase`'s functionality, but you won't need the rest unless you're developing testing frameworks or performing other advanced tasks. Table 17-1 lists the frequently called methods of a `TestCase` instance *t*.

Table 17-1. Methods of an instance `t` of `TestCase`

`assertAlmost Equal`	`assertAlmostEqual(`*first*`,` *second*`, places=7, msg=`**None**`)` Fails and outputs `msg` when *first* `!=` *second* to within `places` decimal digits; otherwise, does nothing. This method is better than `assertEqual` to compare `floats`, since they are approximations that may differ in less significant decimal digits. When producing diagnostic messages if the test fails, `unittest` will assume that *first* is the expected value and *second* is the observed value.
`assertEqual`	`assertEqual(`*first*`,` *second*`, msg=`**None**`)` Fails and outputs `msg` when *first* `!=` *second*; otherwise, does nothing. When producing diagnostic messages if the test fails, `unittest` will assume that *first* is the expected value and *second* is the observed value.
`assertFalse`	`assertFalse(`*condition*`, msg=None)` Fails and outputs `msg` when *condition* is true; otherwise, does nothing.
`assertNotAlmost Equal`	`assertNotAlmostEqual(`*first*`,` *second*`, places=7, msg=`**None**`)` Fails and outputs `msg` when *first* `==` *second* to within `places` decimal digits; otherwise, does nothing.
`assertNotEqual`	`assertNotEqual(`*first*`,` *second*`, msg=`**None**`)` Fails and outputs `msg` when *first* `==` *second*; otherwise, does nothing.

assertRaises	assertRaises(*exceptionSpec*, *callable*, **args*, ***kwargs*)
	Calls *callable*(**args*, ***kwargs*). Fails when the call doesn't raise any exception. When the call raises an exception that does not meet *exceptionSpec*, assertRaises propagates the exception. When the call raises an exception that meets *exceptionSpec*, assertRaises does nothing. *exceptionSpec* can be an exception class or a tuple of classes, just like the first argument of the **except** clause in a **try**/**except** statement.
	The preferred way to use assertRaises is as a context manager—that is, in a **with** statement:
	`with self.assertRaises(exceptionSpec):`
	`    # ...a block of code...`
	Here, the block of code indented in the **with** statement executes, rather than just the *callable* being called with certain arguments. The expectation (which avoids the construct failing) is that the block of code raises an exception meeting the given exception specification (an exception class or a tuple of classes). This alternative approach is more general and readable than passing a callable.

assertRaises Regex	assertRaisesRegex(*exceptionSpec*, *expected_regex*, *callable*, **args*, ***kwargs*)
	Just like assertRaises, but also checks that the exception's error message matches *regex*; *regex* can be a regular expression object or a string pattern to compile into one, and the test (when the expected exception has been raised) checks the error message by calling search on the RE object.
	Just like assertRaises, assertRaisesRegex is best used as a context manager—that is, in a **with** statement:
	`with self.assertRaisesRegex(exceptionSpec, regex):`
	`    # ...a block of code...`

enterContext	enterContext(ctx_manager) **3.11+** Use this call in a TestCase.setup() method. Returns the value from calling ctx_manager.__enter__, and adds ctx_manager.__exit__ to the list of cleanup methods that the framework is to run during the TestCase's cleanup phase.

fail	fail(msg=**None**)
	Fails unconditionally and outputs msg. An example snippet might be:
	`if not complex_check_if_its_ok(some, thing):`
	`    self.fail(`
	`      'Complex checks failed on'`
	`      f' {some}, {thing}'`
	`    )`

setUp	setUp() The framework calls *t*.setUp() just before calling each test case method. setUp in TestCase does nothing; it exists only to let your class override the method when your class needs to perform some preparation for each test.

`subTest`	`subTest(msg=None, **k)` Returns a context manager that can define a portion of a test within a test method. Use `subTest` when a test method runs the same test multiple times with varying parameters. Enclosing these parameterized tests in `subTest` ensures that all the cases will be run, even if some of them fail or raise exceptions.
`tearDown`	`tearDown()` The framework calls `t.tearDown()` just after each test case method. `tearDown` in the base `TestCase` class does nothing; it exists only to let your class override the method when your class needs to perform some cleanup after each test.

In addition, a `TestCase` instance maintains a LIFO stack of *cleanup functions*. When code in one of your tests (or in `setUp`) does something that requires cleanup, call `self.addCleanup`, passing a cleanup callable *f* and optionally positional and named arguments for *f*. To perform the stacked cleanups, you may call `doCleanups`; however, the framework itself calls `doCleanups` after `tearDown`. Table 17-2 lists the signatures of the two cleanup methods of a `TestCase` instance *t*.

Table 17-2. Cleanup methods of an instance t of TestCase

`addCleanup`	`addCleanup(func, *a, **k)` Appends `(func, a, k)` at the end of the cleanups list.

`doCleanups`	`doCleanups()`
	Performs all cleanups, if any are stacked. Substantially equivalent to:
	`while self.list_of_cleanups:`
	`    func, a, k = self.list_of_cleanups.pop()`
	`    func(*a, **k)`
	for a hypothetical stack `self.list_of_cleanups`, plus, of course, error checking and reporting.

Unit tests dealing with large amounts of data

Unit tests must be fast, as you should run them often as you develop. So, when feasible, unit test each aspect of your modules on small amounts of data. This makes your unit tests faster, and lets you embed the data in the test's source code. When you test a function that reads from or writes to a file object, use an instance of the class `io.TextIO` for a text file (or `io.BytesIO` for a binary file, as covered in "In-Memory Files: io.StringIO and io.BytesIO" on page 334) to get a file with the data in memory: this approach is faster than writing to disk, and it requires no cleanup (removing disk files after the tests).

In rare cases, it may be impossible to exercise a module's functionality without supplying and/or comparing data in quantities larger than can be reasonably embedded in a test's source code. In such cases, your unit test must rely on auxiliary, external data files to hold the data to supply to the module it tests, and/or the data it needs to compare to the output. Even then, you're generally better off using instances of the abovementioned `io` classes, rather than directing the tested module to perform actual disk I/O. Even more importantly, we strongly suggest that you generally use stubs to unit test modules that interact with external entities, such as databases, GUIs, or other programs over a network. It's easier to control all aspects of the test when using stubs rather than real external entities. Also, to reiterate, the speed at which you can run unit tests is important, and it's faster to perform simulated operations with stubs than real operations.

Make Test Randomness Reproducible by Supplying a Seed

If your code uses pseudorandom numbers (e.g., as covered in "The random Module" on page 496), you can make it easier to test by ensuring its "random" behavior is *reproducible*: specifically, ensure that it's easy for your tests to call `random.seed` with a known argument, so that the ensuing pseudorandom numbers are fully predictable. This also applies when you use pseudorandom numbers to set up your tests by generating inputs: such generation should default to a known seed, to be used in most testing, keeping the flexibility of changing seeds only for specific techniques such as fuzzing.

Testing with nose2

`nose2` is a `pip`-installable third-party test utility and framework that builds on top of `unittest` to provide additional plug-ins, classes, and decorators to aid in writing and running your test suite. `nose2` will "sniff out" test cases in your project, building its test suite by looking for `unittest` test cases stored in files named *test*.py*.

Here is an example of using `nose2`'s `params` decorator to pass data parameters to a test function:

```
import unittest
from nose2.tools import params

class TestCase(unittest.TestCase):

    @params((5, 5), (-1, 1), ('a', None, TypeError))
    def test_abs_value(self, x, expected, should_raise=None):
        if should_raise is not None:
            with self.assertRaises(should_raise):
                abs(x)
        else:
            assert abs(x) == expected
```

`nose2` also includes additional decorators, the `such` context manager to define groups of test functions, and a plug-in framework to provide testing metafunctions such as logging, debugging, and coverage reporting. For more information, see the online docs.

Testing with pytest

The `pytest` module is a `pip`-installable third-party unit testing framework that introspects a project's modules to find test cases in *test_*.py* or *_test.py* files, with method names starting with `test` at the module level, or in classes with names starting with `Test`. Unlike the built-in `unittest` framework, `pytest` does not require that test cases extend any testing class hierarchy; it runs the discovered test methods, which use Python **`assert`** statements to determine the success or failure of each test.[5] If a test raises any exception other than `AssertionError`, that indicates that there is an error in the test, rather than a simple test failure.

In place of a hierarchy of test case classes, `pytest` provides a number of helper methods and decorators to simplify writing unit tests. The most common methods are listed in Table 17-3; consult the online docs for a more complete list of methods and optional arguments.

Table 17-3. Commonly used `pytest` methods

`approx`	`approx(`*`float_value`*`)`
	Used to support asserts that must compare floating-point values. *`float_value`* can be a single value or a sequence of values:
	`assert 0.1 + 0.2 == approx(0.3)`
	`assert [0.1, 0.2, 0.1+0.2] == approx([0.1, 0.2, 0.3])`

`fail`	`fail(`*`failure_reason`*`)` Forces failure of the current test. More explicit than injecting an **`assert False`** statement, but otherwise equivalent.
`raises`	`raises(`*`expected_exception`*`, match=regex_match)` A context manager that fails unless its context raises an exception *`exc`* such that `isin stance(`*`exc`*`, `*`expected_exception`*`)` is true. When `match` is given, the test fails unless *exc*'s `str` representation also matches `re.search(match, str(`*`exc`*`))`.
`skip`	`skip(`*`skip_reason`*`)` Forces skipping of the current test; use this, for example, when a test is dependent on a previous test that has already failed.
`warns`	`warns(`*`expected_warning`*`, match=`*`regex_match`*`)` Similar to *`raises`*; used to wrap code that tests that an expected warning is raised.

The `pytest.mark` subpackage includes decorators to "mark" test methods with additional test behavior, including the ones listed in Table 17-4.

Test, Debug, Optimize

5 When evaluating `assert` *a* == *b*, `pytest` interprets *a* as the observed value and *b* as the expected value (the reverse of `unittest`).

Table 17-4. Decorators in the `pytest.mark` subpackage

`parametrize`	`@parametrize(`*`args_string`*`, `*`arg_test_values`*`)`
	Calls the decorated test method, setting the arguments named in the comma-separated list *`args_string`* to the values from each argument tuple in *`arg_test_values`*.
	The following code runs `test_is_greater` twice, once with `x=1`, `y=0`, and `expected=True`; and once with `x=0`, `y=1`, and `expected=False`.
	`@pytest.mark.parametrize`
	`("x,y,expected",`
	` [(1, 0, True), (0, 1, False)])`
	`def test_is_greater(x, y, expected):`
	`assert (x > y) == expected`

`skip`, `skipif`	`@skip(`*`skip_reason`*`)`, `@skipif(`*`condition`*`, `*`skip_reason`*`)` Skip a test method, optionally based on some global condition.

Debugging

Since Python's development cycle is fast, the most effective way to debug is often to edit your code to output relevant information at key points. Python has many ways to let your code explore its own state to extract information that may be relevant for debugging. The `inspect` and `traceback` modules specifically support such exploration, which is also known as *reflection* or *introspection*.

Once you have debugging-relevant information, `print` is often the natural way to display it (`pprint`, covered in "The pprint Module" on page 300, is also often a good choice). However, it's frequently even better to *log* debugging information to files. Logging is useful for programs that run unattended (e.g., server programs). Displaying debugging information is just like displaying other information, as covered in Chapter 11. Logging such information is like writing to files (covered in the same chapter); however, Python's standard library supplies a `logging` module, covered in "The logging module" on page 217, to help with this frequent task. As covered in Table 8-3, rebinding `excepthook` in the module `sys` lets your program log error info just before terminating with a propagating exception.

Python also offers hooks to enable interactive debugging. The `pdb` module supplies a simple text-mode interactive debugger. Other powerful interactive debuggers for Python are part of IDEs such as IDLE and various commercial offerings, as mentioned in "Python Development Environments" on page 27; we do not cover these advanced debuggers further in this book.

Before You Debug

Before you embark on lengthy debugging explorations, make sure you have thoroughly checked your Python sources with the tools mentioned in Chapter 2. Such tools catch only a subset of the bugs in your code, but they're much faster than interactive debugging: their use amply pays for itself.

Moreover, again before starting a debugging session, make sure that all the code involved is well covered by unit tests, as described in "The unittest Module" on page 520. As mentioned earlier in the chapter, once you have found a bug, *before* you fix it, add to your suite of unit tests (or, if need be, to the suite of system tests) a test or two that would have found the bug had they been present from the start, and run the tests again to confirm that they now reveal and isolate the bug; only once that is done should you proceed to fix the bug. Regularly following this procedure will help you learn to write better, more thorough tests, ensuring that you end up with a more robust test suite and have greater confidence in the overall, *enduring* correctness of your code.

Remember, even with all the facilities offered by Python, its standard library, and whatever IDE you fancy, debugging is still *hard*. Take this into account even before you start designing and coding: write and run plenty of unit tests, and keep your design and code *simple*, to reduce to the minimum the amount of debugging you will need! Brian Kernighan offers this classic advice: "Debugging is twice as hard as writing the code in the first place. Therefore, if you write the code as cleverly as you can, you are, by definition, not smart enough to debug it." This is part of why "clever" is not a positive word when used to describe Python code, or a coder.

The inspect Module

The `inspect` module supplies functions to get information about all kinds of objects, including the Python call stack (which records all function calls currently executing) and source files. The most frequently used functions of `inspect` are listed in Table 17-5.

Table 17-5. Useful functions of the `inspect` module

`currentframe`	`currentframe()` Returns the frame object for the current function (the caller of `currentframe`). `formatargvalues(*getargvalues(currentframe()))`, for example, returns a string representing the arguments of the calling function.
`getargspec`, `formatargspec`	`getargspec(`*f*`)` **-3.11** Deprecated in Python 3.5, removed in Python 3.11. The forward-compatible way to introspect callables is to call `inspect.signature(`*f*`)` and use the resulting instance of class `inspect.Signature`, covered in the following subsection.

Test, Debug, Optimize

getargvalues, formatargvalues	getargvalues(*f*)
	f is a frame object—for example, the result of a call to the function _getframe in the sys module (covered in "The Frame Type" on page 435) or the function currentframe in the inspect module. getargvalues returns a named tuple with four items: (*args*, *varargs*, *keywords*, *locals*). *args* is the sequence of names of *f*'s function's parameters. *varargs* is the name of the special parameter of form **a*, or **None** when *f*'s function has no such parameter. *keywords* is the name of the special parameter of form ***k*, or **None** when *f*'s function has no such parameter. *locals* is the dictionary of local variables for *f*. Since arguments, in particular, are local variables, the value of each argument can be obtained from *locals* by indexing the *locals* dictionary with the argument's corresponding parameter name.
	formatargvalues accepts one to four arguments that are the same as the items of the named tuple that getargvalues returns, and returns a string with this information. formatargvalues(*getargvalues(*f*)) returns a string with *f*'s arguments in parentheses, in named form, as used in the call statement that created *f*. For example:
	`def f(x=23):`
	`    return inspect.currentframe()`
	`print(inspect.formatargvalues(`
	`      *inspect.getargvalues(f())))`
	`# prints: (x=23)`

getdoc	getdoc(*obj*) Returns the docstring for *obj*, a multiline string with tabs expanded to spaces and redundant whitespace stripped from each line.
getfile, getsourcefile	getfile(*obj*), getsourcefile(*obj*) getfile returns the name of the binary or source file that defined *obj*. Raises TypeError when unable to determine the file (for example, when *obj* is a built-in). getsourcefile returns the name of the source file that defined obj; it raises TypeError when all it can find is a binary file, not the corresponding source file.

getmembers	getmembers(*obj*, filter=**None**)
	Returns all attributes (members), both data and methods (including special methods) of *obj*, as a sorted list of (*name*, *value*) pairs. When filter is not **None**, returns only attributes for which callable filter returns a truthy result when called on the attribute's *value*, equivalent to:
	`((n, v) for n, v in getmembers(obj)`
	`        if filter(v))`

getmodule	getmodule(*obj*) Returns the module that defined *obj*, or **None** when unable to determine it.

`getmro`	`getmro(c)`
	Returns a tuple of bases and ancestors of class *c* in method resolution order (discussed in "Inheritance" on page 129). *c* is the first item in the tuple, and each class appears only once in the tuple. For example:
	`class A: pass`
	`class B(A): pass`
	`class C(A): pass`
	`class D(B, C): pass`
	`for c in inspect.getmro(D):`
	`    print(c.__name__, end=' ')`
	`# prints: D B C A object`

`getsource`, `getsourcelines`	`getsource(obj)`, `getsourcelines(obj)` `getsource` returns a multiline string that is the source code for *obj*, and raises `IOError` if it is unable to determine or fetch it. `getsourcelines` returns a pair: the first item is the source code for *obj* (a list of lines), and the second item is the line number of the first line within its file.
`isbuiltin`, `isclass`, `iscode`, `isframe`, `isfunction`, `ismethod`, `ismodule`, `isroutine`	`isbuiltin(obj)`, etc. Each of these functions accepts a single argument *obj* and returns **`True`** when *obj* is of the kind indicated in the function name. Accepted objects are, respectively: built-in (C-coded) functions, class objects, code objects, frame objects, Python-coded functions (including **`lambda`** expressions), methods, modules, and—for `isroutine`—all methods or functions, either C-coded or Python-coded. These functions are often used as the `filter` argument to `getmembers`.
`stack`	`stack(context=1)` Returns a list of six-item tuples. The first tuple is about `stack`'s caller, the second about the caller's caller, and so on. The items in each tuple are: frame object, filename, line number, function name, list of `context` source lines around the current line, index of current line within the list.

Introspecting callables

To introspect a callable's signature, call `inspect.signature(f)`, which returns an instance *s* of class `inspect.Signature`.

`s.parameters` is a `dict` mapping parameter names to `inspect.Parameter` instances. Call `s.bind(*a, **k)` to bind all parameters to the given positional and named arguments, or `s.bind_partial(*a, **k)` to bind a subset of them: each returns an instance *b* of `inspect.BoundArguments`.

For detailed information and examples of how to introspect callables' signatures through these classes and their methods, see PEP 362.

An example of using inspect

Suppose that somewhere in your program you execute a statement such as:

```
x.f()
```

and unexpectedly receive an AttributeError informing you that object x has no attribute named f. This means that object x is not as you expected, so you want to determine more about x as a preliminary to ascertaining why x is that way and what you should do about it. A simple first approach might be:

```
print(type(x), x)
# or, from v3.8, use an f-string with a trailing '=' to show repr(x)
# print(f'{x=}')
x.f()
```

This will often provide sufficient information to go on; or you might change it to print(type(x), dir(x), x) to see what x's methods and attributes are. But if this isn't sufficient, change the statement to:

```
try:
    x.f()
except AttributeError:
    import sys, inspect
    print(f'x is type {type(x).__name__}, ({x!r})', file=sys.stderr)
    print("x's methods are:", file=sys.stderr, end='')
    for n, v in inspect.getmembers(x, callable):
        print(n, file=sys.stderr, end=' ')
    print(file=sys.stderr)
    raise
```

This example properly uses sys.stderr (covered in Table 8-3), since it displays information related to an error, not program results. The function getmembers of the module inspect obtains the names of all the methods available on x in order to display them. If you often need this kind of diagnostic functionality, you can package it up into a separate function, such as:

```
import sys, inspect
def show_obj_methods(obj, name, show=sys.stderr.write):
    show(f'{name} is type {type(obj).__name__}({obj!r})\n')
    show(f"{name}'s methods are: ")
    for n, v in inspect.getmembers(obj, callable):
       show(f'{n} ')
    show('\n')
```

And then the example becomes just:

```
try:
    x.f()
except AttributeError:
    show_obj_methods(x, 'x')
    raise
```

Good program structure and organization are just as necessary in code intended for diagnostic and debugging purposes as they are in code that implements your program's functionality. See also "The assert Statement" on page 219 for a good technique to use when defining diagnostic and debugging functions.

The traceback Module

The `traceback` module lets you extract, format, and output information about tracebacks that uncaught exceptions normally produce. By default, this module reproduces the formatting Python uses for tracebacks. However, the `traceback` module also lets you exert fine-grained control. The module supplies many functions, but in typical use you need only one of them:

`print_exc` `print_exc(limit=None, file=sys.stderr)`

Call `print_exc` from an exception handler, or from a function called, directly or indirectly, by an exception handler. `print_exc` outputs to file-like object `file` the traceback that Python outputs to `stderr` for uncaught exceptions. When `limit` is an integer, `print_exc` outputs only `limit` traceback nesting levels. For example, when, in an exception handler, you want to cause a diagnostic message just as if the exception propagated, but stop the exception from propagating further (so that your program keeps running and no further handlers are involved), call `traceback.print_exc()`.

The pdb Module

The `pdb` module uses the Python interpreter's debugging and tracing hooks to implement a simple command-line interactive debugger. `pdb` lets you set breakpoints, single-step and jump to source code, examine stack frames, and so on.

To run code under `pdb`'s control, import `pdb`, then call `pdb.run`, passing as the single argument a string of code to execute. To use `pdb` for postmortem debugging (debugging of code that just terminated by propagating an exception at an interactive prompt), call `pdb.pm()` without arguments. To trigger `pdb` directly from your application code, use the built-in function `breakpoint`.

When `pdb` starts, it first reads text files named *.pdbrc* in your home directory and in the current directory. Such files can contain any `pdb` commands, but most often you put `alias` commands in them to define useful synonyms and abbreviations for other commands that you use often.

When `pdb` is in control, it prompts with the string `(Pdb)`, and you can enter `pdb` commands. The command `help` (which you can enter in the abbreviated form `h`) lists the available commands. Call `help` with an argument (separated by a space) to get help about any specific command. You can abbreviate most commands to the first one or two letters, but you must always enter commands in lowercase: `pdb`, like Python itself, is case-sensitive. Entering an empty line repeats the previous command. The most frequently used `pdb` commands are listed in Table 17-6.

Table 17-6. Commonly used `pdb` *commands*

`!`	`!` *`statement`* Executes Python statement *`statement`* with the currently selected stack frame (see the `d` and `u` commands later in this table) as the local namespace.
`alias`, `unalias`	`alias [`*`name`*`[`*`command`*`]]`, `unalias` *`name`* Defines a short form of a frequently used command. *`command`* is any `pdb` command, with arguments, and may contain `%1`, `%2`, and so on to refer to specific arguments passed to the new alias *`name`* being defined, or `%*` to refer to all such arguments. `alias` with no arguments lists currently defined aliases. `alias` *`name`* outputs the current definition of alias *`name`*. `unalias` *`name`* removes an alias.
`args`, `a`	`args` Lists all arguments passed to the function you are currently debugging.
`break`, `b`	`break [`*`location`*`[,`*`condition`*`]]` With no arguments, lists the currently defined breakpoints and the number of times each breakpoint has triggered. With an argument, `break` sets a breakpoint at the given *`location`*. *`location`* can be a line number or a function name, optionally preceded by *`filename`*`:` to set a breakpoint in a file that is not the current one or at the start of a function whose name is ambiguous (i.e., a function that exists in more than one file). When *`condition`* is present, it is an expression to evaluate (in the debugged context) each time the given line or function is about to execute; execution breaks only when the expression returns a truthy value. When setting a new breakpoint, `break` returns a breakpoint number, which you can later use to refer to the new breakpoint in any other breakpoint-related `pdb` command.
`clear`, `cl`	`clear [`*`breakpoint-numbers`*`]` Clears (removes) one or more breakpoints. `clear` with no arguments removes all breakpoints after asking for confirmation. To deactivate a breakpoint temporarily, without removing it, see `disable`, covered below.
`condition`	`condition` *`breakpoint-number`* `[`*`expression`*`]` `condition` *`n expression`* sets or changes the condition on breakpoint *n*. `condition` *n*, without *`expression`*, makes breakpoint *n* unconditional.
`continue`, `c`, `cont`	`continue` Continues execution of the code being debugged, up to a breakpoint, if any.
`disable`	`disable [`*`breakpoint-numbers`*`]` Disables one or more breakpoints. `disable` without arguments disables all breakpoints (after asking for confirmation). This differs from `clear` in that the debugger remembers the breakpoint, and you can reactivate it via `enable`.
`down`, `d`	`down` Moves down one frame in the stack (i.e., toward the most recent function call). Normally, the current position in the stack is at the bottom (at the function that was called most recently and is now being debugged), so `down` can't go further down. However, `down` is useful if you have previously executed the command `up`, which moves the current position upward in the stack.

`enable`	`enable [`*`breakpoint-numbers`*`]` Enables one or more breakpoints. `enable` without arguments enables all breakpoints after asking for confirmation.
`ignore`	`ignore` *`breakpoint-number`* `[`*`count`*`]` Sets the breakpoint's ignore count (to `0` if *`count`* is omitted). Triggering a breakpoint whose ignore count is greater than `0` just decrements the count. Execution stops, presenting you with an interactive `pdb` prompt, only when you trigger a breakpoint whose ignore count is `0`. For example, say that module *fob.py* contains the following code:

```
def f():
    for i in range(1000):
        g(i)
def g(i):
    pass
```

Now consider the following interactive `pdb` session (minor formatting details may change depending on the Python version you're running):

```
>>> import pdb
>>> import fob
>>> pdb.run('fob.f()')
> <string>(1)?()
(Pdb) break fob.g
Breakpoint 1 at C:\mydir\fob.py:5
(Pdb) ignore 1 500
Will ignore next 500 crossings of breakpoint 1.
(Pdb) continue
> C:\mydir\fob.py(5)
g()-> pass
(Pdb) print(i)
500
```

The `ignore` command, as `pdb` says, tells `pdb` to ignore the next `500` hits on breakpoint `1`, which we set at `fob.g` in the previous `break` statement. Therefore, when execution finally stops, the function g has already been called `500` times, as we show by printing its argument `i`, which indeed is now `500`. The ignore count of breakpoint `1` is now `0`; if we execute another `continue` and `print i`, `i` shows as `501`. In other words, once the ignore count decrements to `0`, execution stops every time the breakpoint is hit. If we want to skip some more hits, we must give `pdb` another `ignore` command, setting the ignore count of breakpoint `1` to some value greater than `0` yet again.

`jump`, `j`	`jump` *`line_number`* Sets the next line to execute to the given line number. You can use this to skip over some code by advancing to a line beyond it, or revisit some code that was already run by jumping to a previous line. (Note that a `jump` to a previous source line is not an undo command: any changes to program state made after that line are retained.) `jump` does come with some limitations—for example, you can only jump within the bottom frame, and you cannot jump into a loop or out of a **`finally`** block—but it can still be an extremely useful command.

`list`, `l`	`list [`*`first`*`[, `*`last`*`] ]` Without arguments, lists `11` (eleven) lines centered on the current one, or the next `11` lines if the previous command was also a `list`. Arguments to the `list` command can optionally specify the first and last lines to list within the current file; use a dot (`.`) to indicate the current debug line. The `list` command lists physical lines, counting and including comments and empty lines, not logical lines. `list`'s output marks the current line with `->`; if the current line was reached in the course of handling an exception, the line that raised the exception is marked with `>>`.
`ll`	`ll` Long version of `list`, showing all lines in the current function or frame.
`next`, `n`	`next` Executes the current line, without "stepping into" any function called from the current line. However, hitting breakpoints in functions called directly or indirectly from the current line does stop execution.
`print`, `p`	`print(`*`expression`*`)`, `p` *`expression`* Evaluates *`expression`* in the current context and displays the result.
`quit`, `q`	`quit` Immediately terminates both `pdb` and the program being debugged.
`return`, `r`	`return` Executes the rest of the current function, stopping only at breakpoints, if any.
`step`, `s`	`step` Executes the current line, stepping into any function called from the current line.
`tbreak`	`tbreak [`*`location`*`[, `*`condition`*`]]` Like `break`, but the breakpoint is temporary (i.e., `pdb` automatically removes the breakpoint as soon as the breakpoint is triggered).
`up`, `u`	`up` Moves up one frame in the stack (i.e., away from the most recent function call and toward the calling function).
`where`, `w`	`where` Shows the stack of frames and indicates the current one (i.e., in which frame's context the command `!` executes statements, the command `args` shows arguments, the command `print` evaluates expressions, etc.).

You can also enter a Python expression at the `(Pdb)` prompt, and `pdb` will evaluate it and display the result, just as if you were at the Python interpreter prompt. However, when you enter an expression whose first term coincides with a `pdb` command, the `pdb` command will execute. This is especially problematic when debugging code with single-letter variables like *`p`* and *`q`*. In these cases, you must begin the expression with `!` or precede it with the `print` or `p` command.

Other Debugging Modules

While `pdb` is built into Python, there are third-party packages that provide enhanced features for debugging.

ipdb

Just as `ipython` extends the interactive interpreter provided by Python, `ipdb` adds the same inspection, tab completion, command-line editing, and history features (and magic commands) to `pdb`. Figure 17-1 shows an example interaction.

```
PS M:\dev\python> py -3.11 .\123_puzzle.py
1 -1
> m:\dev\python\123_puzzle.py(11)<module>()
      9 for i in (1, 2, 3):
     10     ipdb.set_trace(context=5, cond=(i==2))
---> 11     try:
     12         print(i, fn(i))
     13     except Exception:

ipdb> i?
Type:           int
String form: 2
Namespace:     Locals
Docstring:
int([x]) -> integer
int(x, base=10) -> integer
```

Figure 17-1. Example of an `ipdb` session

`ipdb` also adds configuration and conditional expressions to its version of `set_trace`, giving more control over when your program is to break out into the debugging session. (In this example, the breakpoint is conditional on `i` being equal to 2.)

pudb

`pudb` is a lightweight "graphical-like" debugger that runs in a terminal console (see Figure 17-2), utilizing the urwid console UI library. It is especially useful when connecting to remote Python environments using terminal sessions such as `ssh`, where a windowed-GUI debugger is not easy to install or run.

Figure 17-2. Example of a pudb session

`pudb` has its own set of debugging commands and interface, which take some practice to use; however, it makes a visual debugging environment handily available when working in tight computing spaces.

The warnings Module

Warnings are messages about errors or anomalies that aren't serious enough to disrupt the program's control flow (as would happen by raising an exception). The `warnings` module affords fine-grained control over which warnings are output and what happens to them. You can conditionally output a warning by calling the function `warn` in the `warnings` module. Other functions in the module let you control how warnings are formatted, set their destinations, and conditionally suppress some warnings or transform some warnings into exceptions.

Classes

Exception classes that represent warnings are not supplied by `warnings`: rather, they are built-ins. The class `Warning` subclasses `Exception` and is the base class for all warnings. You may define your own warning classes, which must subclass `Warning`, either directly or via one of its other existing subclasses—these include:

`DeprecationWarning`
: For use of deprecated features which are still supplied only for backward compatibility

`RuntimeWarning`
: For use of features whose semantics are error prone

`SyntaxWarning`
: For use of features whose syntax is error prone

`UserWarning`
: For other user-defined warnings that don't fit any of the above cases

Objects

Python supplies no concrete "warning objects." Rather, a warning is made up of a *`message`* (a string), a *`category`* (a subclass of `Warning`), and two pieces of information to identify where the warning was raised: *`module`* (the name of the module that raised the warning) and *`lineno`* (the number of the line in the source code that raised the warning). Conceptually, you may think of these as attributes of a warning object *`w`*: we use attribute notation later, strictly for clarity, but no specific object *`w`* actually exists.

Filters

At any time, the `warnings` module keeps a list of active filters for warnings. When you import `warnings` for the first time in a run, the module examines `sys.warnoptions` to determine the initial set of filters. You can run Python with the option **`-W`** to set `sys.warnoptions` for a given run. Do not rely on the initial set of filters being held specifically in `sys.warnoptions`, as this is an implementation detail that may change in future versions of Python.

As each warning *`w`* occurs, `warnings` tests *`w`* against each filter until a filter matches. The first matching filter determines what happens to *`w`*. Each filter is a tuple of five items. The first item, *`action`*, is a string that defines what happens on a match. The other four items, *`message`*, *`category`*, *`module`*, and *`lineno`*, control what it means for *`w`* to match the filter: for a match, all conditions must be satisfied. Here are the meanings of these items (using attribute notation to indicate conceptual attributes of *`w`*):

`message`
: A regular expression pattern string; the match condition is `re.match(`*`message`*`, `*`w`*`.message, re.I)` (the match is case insensitive)

`category`
: `Warning` or a subclass; the match condition is `issubclass(`*`w`*`.category, `*`category`*`)`

`module`
: A regular expression pattern string; the match condition is `re.match(`*`module`*`, `*`w`*`.module)` (the match is case sensitive)

Test, Debug, Optimize

lineno
: An `int`; the match condition is `*lineno* in (*0*, *w*.lineno)`: that is, either *lineno* is `0`, meaning `*w*.lineno` does not matter, or `*w*.lineno` must exactly equal *lineno*

Upon a match, the first field of the filter, the *action*, determines what happens. It can have the following values:

`'always'`
: `*w*.message` is output whether or not *w* has already occurred.

`'default'`
: `*w*.message` is output if, and only if, this is the first time *w* has occurred from this specific location (i.e., this specific `(*w*.module, *w*.location)` pair).

`'error'`
: `*w*.category(*w*.message)` is raised as an exception.

`'ignore'`
: *w* is ignored.

`'module'`
: `*w*.message` is output if, and only if, this is the first time *w* occurs from `*w*.module`.

`'once'`
: `*w*.message` is output if, and only if, this is the first time *w* occurs from any location.

When a module issues a warning, `warnings` adds to that module's global variables a `dict` named `__warningsgregistry__`, if that `dict` is not already present. Each key in the `dict` is a pair `(*message*, *category*)`, or a tuple with three items `(*message*, *category*, *lineno*)`; the corresponding value is **`True`** when further occurrences of that message are to be suppressed. Thus, for example, you can reset the suppression state of all warnings from a module *m* by executing `*m*.__warningsregistry__.clear()`: when you do that, all messages are allowed to get output again (once), even when, for example, they've previously triggered a filter with an *action* of `'module'`.

Functions

The `warnings` module supplies the functions listed in Table 17-7.

Table 17-7. Functions of the `warnings` module

`filter warnings`	`filterwarnings(`*`action`*`, message='.*', category=Warning, module='.*', lineno=0, append=`**`False`**`)` Adds a filter to the list of active filters. When `append` is **`True`**, `filterwarnings` adds the filter after all other existing filters (i.e., appends the filter to the list of existing filters); otherwise, `filterwarnings` inserts the filter before any other existing filter. All components, save *`action`*, have default values that mean "match everything." As detailed above, `message` and `module` are pattern strings for regular expressions, `category` is some subclass of `Warning`, `lineno` is an integer, and *`action`* is a string that determines what happens when a message matches this filter.
`format warning`	`formatwarning(`*`message`*`, `*`category`*`, `*`filename`*`, `*`lineno`*`)` Returns a string that represents the given warning with standard formatting.
`reset warnings`	`resetwarnings()` Removes all filters from the list of filters. `resetwarnings` also discards any filters originally added with the **`-W`** command-line option.
`showwarning`	`showwarning(`*`message`*`, `*`category`*`, `*`filename`*`, `*`lineno`*`, file=sys.stderr)` Outputs the given warning to the given file object. Filter actions that output warnings call `showwarning`, letting the argument `file` default to `sys.stderr`. To change what happens when filter actions output warnings, code your own function with this signature and bind it to `warnings.showwarning`, thus overriding the default implementation.

`warn`	`warn(`*`message`*`, category=UserWarning, stacklevel=1)` Sends a warning so that the filters examine and possibly output it. The location of the warning is the current function (caller of `warn`) if `stacklevel` is 1, or the caller of the current function if `stacklevel` is 2. Thus, passing 2 as the value of `stacklevel` lets you write functions that send warnings on their caller's behalf, such as:
	`def to_unicode(bytestr):`
	`    try:`
	`        return bytestr.decode()`
	`    except UnicodeError:`
	`        warnings.warn(f'Invalid characters in`
	`                      {bytestr!r}',`
	`                      stacklevel=2)`
	`        return bytestr.decode(errors='ignore')`
	Thanks to the parameter `stacklevel=2`, the warning appears to come from the caller of `to_unicode`, rather than from `to_unicode` itself. This is very important when the *`action`* of the filter that matches this warning is `'default'` or `'module'`, since these actions output a warning only the first time the warning occurs from a given location or module.

Optimization

"First make it work. Then make it right. Then make it fast." This quotation, often with slight variations, is widely known as "the golden rule of programming." As far as we've been able to ascertain, the source is Kent Beck, who credits his father with it. This principle is often quoted, but too rarely followed. A negative form, slightly exaggerated for emphasis, is a quotation by Don Knuth (who credits Sir Tony Hoare with it): "Premature optimization is the root of all evil in programming."

Optimization is premature if your code is not working yet, or if you're not sure what, precisely, your code should be doing (since then you cannot be sure if it's working). First make it work: ensure that your code is correctly performing exactly the tasks it is *meant* to perform.

Optimization is also premature if your code is working but you are not satisfied with the overall architecture and design. Remedy structural flaws before worrying about optimization: first make it work, then make it right. These steps are not optional; working, well-architected code is *always* a must.[6]

Having a good test suite is key before attempting any optimization. After all, the purpose of optimization is to increase speed or reduce memory consumption—or both—without changing the code's behavior.

In contrast, you don't always need to make it fast. Benchmarks may show that your code's performance is already acceptable after the first two steps. When performance is not acceptable, profiling often shows that all performance issues are in a small part of the code, with your program spending perhaps 80 or 90% of its time in 10 to 20% of the code.[7] Such performance-crucial regions of your code are known as *bottlenecks*, or *hot spots*. It's a waste of effort to optimize large portions of code that account for, say, 10 percent of your program's running time. Even if you made that part run 10 times as fast (a rare feat), your program's overall runtime would only decrease by 9%,[8] a speedup no user would likely even notice. If optimization is needed, focus your efforts where they matter: on bottlenecks. You can often optimize bottlenecks while keeping your code 100% pure Python, thus not preventing future porting to other Python implementations.

Developing a Fast-Enough Python Application

Start by designing, coding, and testing your application in Python, using available extension modules if they save you work. This takes much less time than it would with a classic compiled language. Then benchmark the application to find out if the resulting code is fast enough. Often it is, and you're done—congratulations! Ship it!

Since much of Python itself is coded in highly optimized C (as are many of its standard library and extension modules), your application may even turn out to already be faster than typical C code. However, if the application is too slow, you need, first and foremost, to rethink your algorithms and data structures. Check for

6 "Oh, but I'll only be running this code for a short time!" is *not* an excuse to get sloppy: the Russian proverb "nothing is more permanent than a temporary solution" is particularly applicable in software. All over the world, plenty of "temporary" code performing crucial tasks is over 50 years old.

7 A typical case of the Pareto principle in action.

8 Per Amdahl's law.

bottlenecks due to application architecture, network traffic, database access, and operating system interactions. For many applications, each of these factors is more likely than language choice, or coding details, to cause slowdowns. Tinkering with large-scale architectural aspects can often dramatically speed up an application, and Python is an excellent medium for such experimentation. If you're using a version control system (and you ought to be!), it should be easy to create experimental branches or clones where you can try out different techniques to see which—if any—deliver significant improvements, all without jeopardizing your working code. You can then merge back any improvements that pass your tests.

If your program is still too slow, profile it: find out where the time is going! As we previously mentioned, applications often exhibit computational bottlenecks, with small areas of the source code accounting for the vast majority of the running time. Optimize the bottlenecks, applying the techniques suggested in the rest of this chapter.

If normal Python-level optimizations still leave some outstanding computational bottlenecks, you can recode those as Python extension modules, as covered in Chapter 25. In the end, your application will run at roughly the same speed as if you had coded it all in C, C++, or FORTRAN—or faster, when large-scale experimentation has let you find a better architecture. Your overall programming productivity with this process will not be much lower than if you had coded everything in Python. Future changes and maintenance are easy, since you use Python to express the overall structure of the program, and lower-level, harder-to-maintain languages for only a few specific computational bottlenecks.

As you build applications in a given area following this process, you will accumulate a library of reusable Python extension modules. You will therefore become more and more productive at developing other fast-running Python applications in the same field.

Even if external constraints eventually force you to recode your whole application in a lower-level language, you'll still be better off for having started in Python. Rapid prototyping has long been acknowledged as the best way to get software architecture right. A working prototype lets you check that you have identified the right problems and taken a good path to their solution. A prototype also affords the kind of large-scale architectural experimentation that can make a real difference in performance. You can migrate your code gradually to other languages by way of extension modules, if need be, and the application remains fully functional and testable at each stage. This ensures against the risk of compromising a design's architectural integrity in the coding stage.

Even if you are required to use a low-level language for the entire application, it can often be more productive to write it in Python first (especially if you are new to the application's domain). Once you have a working Python version, you can experiment with the user or network interface or library API, and with the architecture. Also, it is much easier to find and fix bugs and to make changes in Python code than in lower-level languages. At the end, you'll know the code so well that porting to a lower-level language should be very fast and straightforward, safe in the knowledge that most of the design mistakes were made and fixed in the Python implementation.

The resulting software will be faster and more robust than if all of the coding had been lower-level from the start, and your productivity—while not quite as good as with a pure Python application—will still be higher than if you had been coding at a lower level throughout.

Benchmarking

Benchmarking (also known as *load testing*) is similar to system testing: both activities are much like running the program for production purposes. In both cases, you need to have at least some subset of the program's intended functionality working, and you need to use known, reproducible inputs. For benchmarking, you don't need to capture and check your program's output: since you make it work and make it right before you make it fast, you're already fully confident about your program's correctness by the time you load test it. You do need inputs that are representative of typical system operation—ideally ones that are likely to pose the greatest challenges to your program's performance. If your program performs several kinds of operations, make sure you run some benchmarks for each different kind of operation.

Elapsed time as measured by your wristwatch is probably precise enough to benchmark most programs. A 5 or 10% difference in performance, except in programs with very peculiar constraints, makes no practical difference to a program's real-life usability. (Programs with hard real-time constraints are another matter, since they have needs very different from those of normal programs in most respects.)

When you benchmark "toy" programs or snippets in order to help you choose an algorithm or data structure, you may need more precision: the `timeit` module of Python's standard library (covered in "The timeit module" on page 552) is quite suitable for such tasks. The benchmarking discussed in this section is of a different kind: it is an approximation of real-life program operation for the sole purpose of checking whether the program's performance on each task is acceptable, before embarking on profiling and other optimization activities. For such "system" benchmarking, a situation that approximates the program's normal operating conditions is best, and high accuracy in timing is not all that important.

Large-Scale Optimization

The aspects of your program that are most important for performance are large-scale ones: your choice of overall architecture, algorithms, and data structures.

The performance issues that you must often take into account are those connected with the traditional big-O notation of computer science. Informally, if you call *N* the input size of an algorithm, big-O notation expresses algorithm performance, for large values of *N*, as proportional to some function of *N*. (In precise computer science lingo, this should be called big-Theta notation, but in real life, programmers always call it big-O, perhaps because an uppercase Theta looks a bit like an O with a dot in the center!)

An O(1) algorithm (also known as "constant time") is one that takes a certain amount of time not growing with *N*. An O(*N*) algorithm (also known as "linear time") is one where, for large enough *N*, handling twice as much data takes about twice as much time, three times as much data takes three times as much time, and so on, proportionally to *N*. An O(N^2) algorithm (also known as a "quadratic time" algorithm) is one where, for large enough *N*, handling twice as much data takes about four times as much time, three times as much data takes nine times as much time, and so on, growing proportionally to *N* squared. Identical concepts and notation are used to describe a program's consumption of memory ("space") rather than of time.

To find more information on big-O notation, and about algorithms and their complexity, any good book about algorithms and data structures can help; we recommend Magnus Lie Hetland's excellent book *Python Algorithms: Mastering Basic Algorithms in the Python Language*, 2nd edition (Apress).

To understand the practical importance of big-O considerations in your programs, consider two different ways to accept all items from an input iterable and accumulate them into a list in reverse order:

```
def slow(it):
    result = []
    for item in it:
        result.insert(0, item)
    return result

def fast(it):
    result = []
    for item in it:
        result.append(item)
    result.reverse()
    return result
```

We could express each of these functions more concisely, but the key difference is best appreciated by presenting the functions in these elementary terms. The function `slow` builds the result list by inserting each input item *before* all previously received ones. The function `fast` appends each input item *after* all previously received ones, then reverses the result list at the end. Intuitively, one might think that the final reversing represents extra work, and therefore `slow` should be faster than `fast`. But that's not the way things work out.

Each call to `result.append` takes roughly the same amount of time, independent of how many items are already in the list `result`, since there is (nearly) always a free slot for an extra item at the end of the list (in pedantic terms, `append` is *amortized* `O(1)`, but we don't cover amortization in this book). The **`for`** loop in the function `fast` executes *N* times to receive *N* items. Since each iteration of the loop takes a constant time, overall loop time is O(*N*). `result.reverse` also takes time O(*N*), as it is directly proportional to the total number of items. Thus, the total running time of `fast` is $O(N)$. (If you don't understand why a sum of two quantities, each $O(N)$, is also $O(N)$, consider that the sum of any two linear functions of *N* is also a linear function of *N*—and "being $O(N)$" has exactly the same meaning as "consuming an amount of time that is a linear function of *N*.")

On the other hand, each call to `result.insert` makes space at slot `0` for the new item to insert, moving all items that are already in list `result` forward one slot. This takes time proportional to the number of items already in the list. The overall amount of time to receive *N* items is therefore proportional to `1+2+3+...N-1`, a sum whose value is $O(N^2)$. Therefore, the total running time of `slow` is $O(N^2)$.

It's almost always worth replacing an $O(N^2)$ solution with an $O(N)$ one, unless you can somehow assign rigorous small limits to input size *N*. If *N* can grow without very strict bounds, the $O(N^2)$ solution turns out to be disastrously slower than the $O(N)$ one for large values of *N*, no matter what the proportionality constants in each case may be (and no matter what profiling tells you). Unless you have other $O(N^2)$ or even worse bottlenecks elsewhere that you can't eliminate, a part of the program that is $O(N^2)$ turns into the program's bottleneck, dominating runtime for large values of *N*. Do yourself a favor and watch out for the big-O: all other performance issues, in comparison, are usually almost insignificant.

Incidentally, you can make the function `fast` even faster by expressing it in more idiomatic Python. Just replace the first two lines with the following single statement:

```
result = list(it)
```

This change does not affect `fast`'s big-O character (`fast` is still $O(N)$ after the change), but does speed things up by a large constant factor.

Simple Is Better than Complex, and Usually Faster!

More often than not, in Python, the simplest, clearest, most direct and idiomatic way to express something is also the fastest.

Choosing algorithms with good big-O performance is roughly the same task in Python as in any other language. You just need a few hints about the big-O performance of Python's elementary building blocks, and we provide them in the following sections.

List operations

Python lists are internally implemented as *vectors* (also known as *dynamic arrays*), not as "*linked* lists." This implementation choice determines the performance characteristics of Python lists, in big-O terms.

Chaining two lists *L1* and *L2*, of length *N1* and *N2* (i.e., *L1*+*L2*) is $O(N1+N2)$. Multiplying a list *L* of length *N* by integer *M* (i.e., *L***M*) is $O(N*M)$. Accessing or rebinding any list item is `O(1)`. `len()` on a list is also `O(1)`. Accessing any slice of length *M* is `O(M)`. Rebinding a slice of length *M* with one of identical length is also `O(M)`. Rebinding a slice of length *M1* with one of different length *M2* is `O(M1+M2+N1)`, where *N1* is the number of items *after* the slice in the target list (so, length-changing slice rebindings are relatively cheap when they occur at the *end* of a list, but costlier when they occur at the *beginning* or around the middle of a long list). If you need first-in, first-out operations, a list is probably not the fastest data structure for the purpose: instead, try the type `collections.deque`, covered in "deque" on page 268.

Most list methods, as shown in Table 3-5, are equivalent to slice rebindings and have equivalent big-O performance. The methods `count`, `index`, `remove`, and `reverse`, and the operator **`in`**, are `O(N)`. The method `sort` is generally `O(N log N)`, but `sort` is highly optimized[9] to be `O(N)` in some important special cases, such as when the list is already sorted or reverse-sorted except for a few items. `range(a, b, c)` is `O(1)`, but looping on all items of the result is `O((b - a) // c)`.

String operations

Most methods on a string of length *N* (be it bytes or Unicode) are `O(N)`. `len(astring)` is `O(1)`. The fastest way to produce a copy of a string with transliterations and/or removal of specified characters is the string's method `translate`. The single most practically important big-O consideration involving strings is covered in "Building up a string from pieces" on page 554.

Dictionary operations

Python `dicts` are implemented with hash tables. This implementation choice determines all the performance characteristics of Python dictionaries, in big-O terms.

Accessing, rebinding, adding, or removing a dictionary item is `O(1)`, as are the methods `get`, `setdefault`, and `popitem`, and the operator **`in`**. `d1.update(d2)` is `O(len(d2))`. `len(adict)` is `O(1)`. The methods `keys`, `items`, and `values` are `O(1)`, but looping on all items of the iterators those methods return is `O(N)`, as is looping directly on a `dict`.

When the keys in a dictionary are instances of classes that define `__hash__` and equality comparison methods, dictionary performance is of course affected by those methods. The performance indications presented in this section hold when hashing and equality comparison on keys are `O(1)`.

Set operations

Python sets, like `dicts`, are implemented with hash tables. All performance characteristics of sets are, in big-O terms, the same as for dictionaries.

9 Using the invented-for-Python adaptive sorting algorithm Timsort.

Adding or removing an item in a set is `O(1)`, as is the operator **`in`**. `len(aset)` is `O(1)`. Looping on a set is `O(N)`. When the items in a set are instances of classes that define `__hash__` and equality comparison methods, set performance is of course affected by those methods. The performance hints presented in this section hold when hashing and equality comparison on items are `O(1)`.

Summary of big-O times for operations on Python built-in types

Let *L* be any list, *T* any string (`str` or `bytes`), *D* any `dict`, *S* any `set` (with, say, numbers as items, just for the purpose of ensuring `O(1)` hashing and comparison), and *x* any number (ditto):

`O(1)`
: `len(L)`, `len(T)`, `len(D)`, `len(S)`, `L[i]`, `T[i]`, `D[i]`, `del D[i]`, **`if`** *x* **`in`** `D`, **`if`** *x* **`in`** *S*, `S.add(x)`, `S.remove(x)`, appends or removals to/from the very right end of *L*

`O(N)`
: Loops on *L*, *T*, *D*, *S*, general appends or removals to/from *L* (except at the very right end), all methods on *T*, **`if`** *x* **`in`** *L*, **`if`** *x* **`in`** *T*, most methods on *L*, all shallow copies

`O(N log N)`
: `L.sort()`, mostly (but `O(N)` if *L* is already nearly sorted or reverse sorted)

Profiling

As mentioned at the start of this section, most programs have *hot spots*: relatively small regions of source code that account for most of the time elapsed during a program run. Don't try to guess where your program's hot spots are: a programmer's intuition is notoriously unreliable in this field. Instead, use the Python standard library module `profile` to collect profile data over one or more runs of your program, with known inputs. Then use the module `pstats` to collate, interpret, and display that profile data.

To gain accuracy, you can calibrate the Python profiler for your machine (i.e., determine what overhead profiling incurs on that machine). The `profile` module can then subtract this overhead from the times it measures, making profile data you collect closer to reality. The standard library module `cProfile` has similar functionality to `profile`; `cProfile` is preferable, since it's faster, which means it imposes less overhead.

There are also many third-party profiling tools worth considering, such as pyinstrument and Eliot; an excellent article by Itamar Turner-Trauring explains the basics and advantages of each of these tools.

The profile module

The `profile` module supplies one often-used function:

`run` `run(code, filename=None)`

code is a string that is usable with `exec`, normally a call to the main function of the program you're profiling. `filename` is the path of a file that `run` creates or rewrites with profile data. Usually, you call `run` a few times, specifying different filenames and different arguments to your program's main function, in order to exercise various program parts in proportion to your expectations about their use "in real life." Then, you use the `pstats` module to display collated results across the various runs.

You may call `run` without a `filename` to get a summary report, similar to the one the `pstats` module provides, on standard output. However, this approach gives you no control over the output format, nor any way to consolidate several runs into one report. In practice, you should rarely use this feature: it's best to collect profile data into files, then use `pstats`.

The `profile` module also supplies the class `Profile` (discussed briefly in the next section). By instantiating `Profile` directly, you can access advanced functionality, such as the ability to run a command in specified local and global dictionaries. We do not cover such advanced functionality of the class `profile.Profile` further in this book.

Calibration

To calibrate `profile` for your machine, use the class `Profile`, which `profile` supplies and internally uses in the function `run`. An instance *p* of `Profile` supplies one method you use for calibration:

`calibrate` `p.calibrate(N)`

Loops *N* times, then returns a number that is the profiling overhead per call on your machine. *N* must be large if your machine is fast. Call `p.calibrate(10000)` a few times and check that the various numbers it returns are close to each other, then pick the smallest one of them. If the numbers vary a lot, try again with a larger value of *N*.

The calibration procedure can be time-consuming. However, you need to perform it only once, repeating it only when you make changes that could alter your machine's characteristics, such as applying patches to your operating system, adding memory, or changing your Python version. Once you know your machine's overhead, you can tell `profile` about it each time you import it, right before using `profile.run`. The simplest way to do this is as follows:

```
import profile
profile.Profile.bias = ...the overhead you measured...
profile.run('main()', 'somefile')
```

The pstats module

The `pstats` module supplies a single class, `Stats`, to analyze, consolidate, and report on the profile data contained in one or more files written by the function `profile.run`. Its constructor has the signature:

`Stats` **class** `Stats(filename, *filenames, stream=sys.stdout)`

Instantiates `Stats` with one or more filenames of files of profile data written by the function `profile.run`, with profiling output sent to `stream`.

An instance *s* of the class `Stats` provides methods to add profile data and sort and output results. Each method returns *s*, so you can chain many calls in the same expression. *s*'s main methods are listed in Table 17-8.

Table 17-8. Methods of an instance s of class Stats

`add`	`add(`*`filename`*`)` Adds another file of profile data to the set that *s* is holding for analysis.
`print_callees`, `print_callers`	`print_callees(*`*`restrictions`*`)`, `print_callers(*`*`restrictions`*`)` Outputs the list of functions in *s*'s profile data, sorted according to the latest call to *s*`.sort_stats` and subject to given restrictions, if any. You can call each printing method with zero or more *`restrictions`*, to be applied one after the other, in order, to reduce the number of output lines. A restriction that is an `int` *n* limits the output to the first *n* lines. A restriction that is a `float` *f* between `0.0` and `1.0` limits the output to a fraction *f* of the lines. A restriction that is a string is compiled as a regular expression pattern (covered in "Regular Expressions and the re Module" on page 305); only lines that satisfy a `search` method call on the regular expression are output. Restrictions are cumulative. For example, *s*`.print_callees(10, 0.5)` outputs the first 5 lines (half of 10). Restrictions apply only after the summary and header lines: the summary and header lines are output unconditionally. Each function *f* in the output is accompanied by the list of *f*'s callers (functions that called *f*) or *f*'s callees (functions that *f* called), according to the name of the method.
`print_stats`	`print_stats(*`*`restrictions`*`)` Outputs statistics about *s*'s profile data, sorted according to the latest call to *s*`.sort_stats` and subject to given restrictions, if any, as covered in `print_callees` and `print_callers`, above. After a few summary lines (date and time on which profile data was collected, number of function calls, and sort criteria used), the output—absent restrictions—is one line per function, with six fields per line, labeled in a header line. `print_stats` outputs the following fields for each function *f*: 1. Total number of calls to *f* 2. Total time spent in *f*, exclusive of other functions that *f* called 3. Total time per call to *f* (i.e., field 2 divided by field 1) 4. Cumulative time spent in *f*, and all functions directly or indirectly called from *f* 5. Cumulative time per call to *f* (i.e., field 4 divided by field 1) 6. The name of function *f*

`sort_stats`	`sort_stats(*keys)`
	Gives one or more keys on which to sort future output. Each key is either a string or a member of the enum `pstats.SortKey`. The sort is descending for keys that indicate times or numbers, and alphabetical for key `'nfl'`. The most frequently used keys when calling `sort_stats` are:
	
	`SortKey.CALLS` or `'calls'`
	Number of calls to the function (like field 1 in the `print_stats` output)
	
	`SortKey.CUMULATIVE` or `'cumulative'`
	Cumulative time spent in the function and all functions it called (like field 4 in the `print_stats` output)
	
	`SortKey.NFL` or `'nfl'`
	Name of the function, its module, and the line number of the function in its file (like field 6 in the `print_stats` output)
	
	`SortKey.TIME` or `'time'`
	Total time spent in the function itself, exclusive of functions it called (like field 2 in the `print_stats` output)

`strip_dirs`	`strip_dirs()` Alters *s* by stripping directory names from all module names to make future output more compact. *s* is unsorted after `s.strip_dirs`, and therefore you normally call `s.sort_stats` right after calling `s.strip_dirs`.

Small-Scale Optimization

Fine-tuning of program operations is rarely important. It may make a small but meaningful difference in some particularly hot spot, but it is hardly ever a decisive factor. And yet, fine-tuning—in the pursuit of mostly irrelevant microefficiencies—is where a programmer's instincts are likely to lead them. It is in good part because of this that most optimization is premature and best avoided. The most that can be said in favor of fine-tuning is that, if one idiom is *always* speedier than another when the difference is measurable, then it's worth your while to get into the habit of always using the speedier way.[10]

In Python, if you do what comes naturally, choosing simplicity and elegance, you typically end up with code that has good performance and is clear and maintainable. In other words, *let Python do the work*: when Python provides a simple, direct way to perform a task, chances are that it's also the fastest way. In a few cases, an approach that may not be intuitively preferable still offers performance advantages, as discussed in the rest of this section.

10 A once-slower idiom may be optimized in some future version of Python, so it's worth redoing `timeit` measurements to check for this when you upgrade to newer versions of Python.

The simplest optimization is to run your Python programs using **python -O** or **-OO**. **-OO** makes little difference to performance compared to **-O** but may save some memory, as it removes docstrings from the bytecode, and memory is sometimes (indirectly) a performance bottleneck. The optimizer is not powerful in current releases of Python, but it may gain you performance advantages on the order of 5-10% (and potentially larger if you make use of **assert** statements and **if __debug__:** guards, as suggested in "The assert Statement" on page 219). The best aspect of **-O** is that it costs nothing—as long as your optimization isn't premature, of course (don't bother using **-O** on a program you're still developing).

The timeit module

The standard library module `timeit` is handy for measuring the precise performance of specific snippets of code. You can import `timeit` to use `timeit`'s functionality in your programs, but the simplest and most normal use is from the command line:

```
$ python -m timeit -s 'setup statement(s)' 'statement(s) to be timed'
```

The "setup statement" is executed only once, to set things up; the "statements to be timed" are executed repeatedly, to accurately measure the average time they take.

For example, say you're wondering about the performance of `x=x+1` versus `x+=1`, where `x` is an `int`. At a command prompt, you can easily try:

```
$ python -m timeit -s 'x=0' 'x=x+1'
1000000 loops, best of 3: 0.0416 usec per loop
$ python -m timeit -s 'x=0' 'x+=1'
1000000 loops, best of 3: 0.0406 usec per loop
```

and find out that performance is, for all intents and purposes, the same in both cases (a tiny difference, such as the 2.5% in this case, is best regarded as "noise").

Memoizing

Memoizing is the technique of saving values returned from a function that is called repeatedly with the same argument values. When the function is called with arguments that have not been seen before, a memoizing function computes the result, and then saves the arguments used to call it and the corresponding result in a cache. When the function is called again later with the same arguments, the function just looks up the computed value in the cache instead of rerunning the function calculation logic. In this way, the calculation is performed just once for any particular argument or arguments.

Here is an example of a function for calculating the sine of a value given in degrees:

```
import math
def sin_degrees(x):
    return math.sin(math.radians(x))
```

If we determined that sin_degrees was a bottleneck, and was being repeatedly called with the same values for x (such as the integer values from 0 to 360, as you might use when displaying an analog clock), we could add a memoizing cache:

```
_cached_values = {}
def sin_degrees(x):
    if x not in _cached_values:
        _cached_values[x] = math.sin(math.radians(x))
    return _cached_values[x]
```

For functions that take multiple arguments, the tuple of argument values would be used for the cache key.

We defined *_cached_values* outside the function, so that it is not reset each time we call the function. To explicitly associate the cache with the function, we can utilize Python's object model, which allows us to treat functions as objects and assign attributes to them:

```
def sin_degrees(x):
    cache = sin_degrees._cached_values
    if x not in cache:
        cache[x] = math.sin(math.radians(x))
    return cache[x]
sin_degrees._cached_values = {}
```

Caching is a classic approach to gain performance at the expense of using memory (the *time–memory trade-off*). The cache in this example is unbounded, so, as sin_degrees is called with many different values of x, the cache will continue to grow, consuming more and more program memory. Caches are often configured with an *eviction policy*, which determines when values can be removed from the cache. Removing the oldest cached value is a common eviction policy. Since Python keeps dict entries in insertion order, the "oldest" key will be the first one found if we iterate over the dict:

```
def sin_degrees(x):
    cache = sin_degrees._cached_values
    if x not in cache:
        cache[x] = math.sin(math.radians(x))
        # remove oldest cache entry if exceed maxsize limit
        if len(cache) > sin_degrees._maxsize:
            oldest_key = next(iter(cache))
            del cache[oldest_key]
    return cache[x]
sin_degrees._cached_values = {}
sin_degrees._maxsize = 512
```

You can see that this starts to complicate the code, with the original logic for computing the sine of a value given in degrees hidden inside all the caching logic. The Python stdlib module functools includes caching decorators lru_cache, **3.9+** cache, and **3.8+** cached_property to perform memoization cleanly. For example:

Test, Debug, Optimize

```python
import functools
@functools.lru_cache(maxsize=512)
def sin_degrees(x):
    return math.sin(math.radians(x))
```

The signatures for these decorators are described in detail in "The functools Module" on page 269.

> **Caching Floating-Point Values Can Give Undesirable Behavior**
>
> As was described in "Floating-Point Values" on page 485, comparing `float` values for equality can return **`False`** when the values are actually within some expected tolerance for being considered equal. With an unbounded cache, a cache containing `float` keys may grow unexpectedly large by caching multiple values that differ only in the 18th decimal place. For a bounded cache, many `float` keys that are very nearly equal may cause the unwanted eviction of other values that are significantly different.
>
> All the cache techniques listed here use equality matching, so code for memoizing a function with one or more `float` arguments should take extra steps to cache rounded values, or use `math.isclose` for matching.

Precomputing a lookup table

In some cases, you can predict all the values that your code will use when calling a particular function. This allows you to precompute the values and save them in a lookup table. For example, in our application that is going to compute the `sin` function for the integer degree values `0` to `360`, we can perform this work just once at program startup and keep the results in a Python `dict`:

```python
_sin_degrees_lookup = {x: math.sin(math.radians(x))
                       for x in range(0, 360+1)}
sin_degrees = _sin_degrees_lookup.get
```

Binding `sin_degrees` to the `_sin_degrees_lookup` `dict`'s `get` method means the rest of our program can still call `sin_degrees` as a function, but now the value retrieval occurs at the speed of a `dict` lookup, with no additional function overhead.

Building up a string from pieces

The single Python "anti-idiom" that is most likely to damage your program's performance, to the point that you should *never* use it, is to build up a large string from pieces by looping on string concatenation statements such as `big_string += piece`. Python strings are immutable, so each such concatenation means that Python must free the M bytes previously allocated for `big_string`, and allocate and fill $M + K$ bytes for the new version. Doing this repeatedly in a loop, you end up with roughly $O(N^2)$ performance, where N is the total number of characters. More often than not, getting `O(N²)` performance where `O(N)` is easily available is a disaster.[11] On some platforms, things may be even bleaker due to memory fragmentation effects caused by freeing many areas of progressively larger sizes.

To achieve `O(N)` performance, accumulate intermediate pieces in a list, rather than building up the string piece by piece. Lists, unlike strings, are mutable, so appending to a list is `O(1)` (amortized). Change each occurrence of `big_string += piece` into `temp_list.append(piece)`. Then, when you're done accumulating, use the following code to build your desired string result in `O(N)` time:

```
big_string = ''.join(temp_list)
```

Using a list comprehension, generator expression, or other direct means (such as a call to `map`, or use of the standard library module `itertools`) to build `temp_list` may often offer further (substantial, but not big-O) optimization over repeated calls to `temp_list.append`. Other `O(N)` ways to build up big strings, which a few Python programmers find more readable, are to concatenate the pieces to an instance of `array.array('u')` with the array's `extend` method, use a `bytearray`, or write the pieces to an instance of `io.TextIO` or `io.BytesIO`.

In the special case where you want to output the resulting string, you may gain a further small slice of performance by using `writelines` on `temp_list` (never building `big_string` in memory). When feasible (i.e., when you have the output file object open and available in the loop, and the file is buffered), it's just as effective to perform a `write` call for each `piece`, without any accumulation.

Although not nearly as crucial as `+=` on a big string in a loop, another case where removing string concatenation may give a slight performance improvement is when you're concatenating several values in an expression:

```
oneway = str(x) + ' eggs and ' + str(y) + ' slices of ' + k + ' ham'
another = '{} eggs and {} slices of {} ham'.format(x, y, k)
yetanother = f'{x} eggs and {y} slices of {k} ham'
```

Formatting strings using the `format` method or f-strings (discussed in Chapter 8) is often a good performance choice, as well as being more idiomatic and thereby clearer than concatenation approaches. On a sample run of the preceding example, the `format` approach is more than twice as fast as the (perhaps more intuitive) concatenation, and the f-string approach is more than twice as fast as `format`.

Test, Debug, Optimize

11 Even though current Python implementations bend over backward to help reduce the performance hit of this specific, terrible, but common anti-pattern, they can't catch every occurrence, so don't count on that!

Searching and sorting

The operator **in**, the most natural tool for searching, is O(1) when the righthand-side operand is a set or dict, but O(*N*) when the righthand-side operand is a string, list, or tuple. If you must perform many such checks on a container, you're *much* better off using a set or dict, rather than a list or tuple, as the container. Python sets and dicts are highly optimized for searching and fetching items by key. Building the set or dict from other containers, however, is O(*N*), so for this crucial optimization to be worthwhile, you must be able to hold on to the set or dict over several searches, possibly altering it apace as the underlying sequence changes.

The sort method of Python lists is also a highly optimized and sophisticated tool. You can rely on sort's performance. Most functions and methods in the standard library that perform comparisons accept a key argument to determine how, exactly, to compare items. You provide a key function, which computes a key value for each element in the list. The list elements are sorted by their key values. For instance, you might write a key function for sorting objects based on an attribute *attr* as **lambda** ob: ob.*attr*, or one for sorting dicts by dict key '*attr*' as **lambda** d: d['*attr*']. (The attrgetter and itemgetter methods of the operator module are useful alternatives to these simple key functions; they're clearer and sharper than **lambda** and offer performance gains as well.)

Older versions of Python used a cmp function, which would take list elements in pairs (*A*, *B*) and return -1, 0, or 1 for each pair depending on which of *A* < *B*, *A* == *B*, or *A* > *B* is true. Sorting using a cmp function is very slow, as it may have to compare every element to every other element (potentially O(N^2) performance). The sort function in current Python versions no longer accepts a cmp function argument. If you are migrating ancient code and only have a function suitable as a cmp argument, you can use functools.cmp_to_key to build from it a key function suitable to pass as the new key argument.

However, several functions in the module heapq, covered in "The heapq Module" on page 271, do not accept a key argument. In such cases, you can use the DSU idiom, covered in "The Decorate–Sort–Undecorate Idiom" on page 273. (Heaps are well worth keeping in mind, since in some cases they can save you from having to perform sorting on all of your data.)

Avoid exec and from ... import *

Code in a function runs faster than code at the top level in a module, because access to a function's local variables is faster than access to globals. If a function contains an exec without explicit dicts, however, the function slows down. The presence of such an exec forces the Python compiler to avoid the modest but important optimization it normally performs regarding access to local variables, since the exec might alter the function's namespace. A **from** statement of the form:

```
from my_module import *
```

wastes performance too, since it also can alter a function's namespace unpredictably, and therefore inhibits Python's local-variable optimization.

`exec` itself is also quite slow, and even more so if you apply it to a string of source code rather than to a code object. By far the best approach—for performance, for correctness, and for clarity—is to avoid `exec` altogether. It's most often possible to find better (faster, more robust, and clearer) solutions. If you *must* use `exec`, *always* use it with explicit `dict`s, although avoiding `exec` altogether is *far* better, if at all feasible. If you need to `exec` a dynamically obtained string more than once, `compile` the string just once and then repeatedly `exec` the resulting code object.

`eval` works on expressions, not on statements; therefore, while still slow, it avoids some of the worst performance impacts of `exec`. With `eval`, too, you're best advised to use explicit `dict`s. As with `exec`, if you need multiple evaluations of the same dynamically obtained string, `compile` the string once and then repeatedly `eval` the resulting code object. Avoiding `eval` altogether is even better.

See "Dynamic Execution and exec" on page 430 for more details and advice about `exec`, `eval`, and `compile`.

Short-circuiting of Boolean expressions

Python evaluates Boolean expressions from left to right according to the precedence of the operations **`not`**, **`and`**, and **`or`**. When, from evaluating just the leading terms, Python can determine that the overall expression must be **`True`** or **`False`**, it skips the rest of the expression. This feature is known as *short-circuiting*, so called because Python bypasses unneeded processing the same way an electrical short bypasses parts of an electrical circuit.

In this example, both conditions must be **`True`** to continue:

```
if slow_function() and fast_function():
    # ... proceed with processing ...
```

When `fast_function` is going to return **`False`**, it's faster to evaluate it first, potentially avoiding the call to `slow_function` altogether:

```
if fast_function() and slow_function():
    # ... proceed with processing ...
```

This optimization also applies when the operator is **`or`**, when either case must be **`True`** to continue: when `fast_function` returns **`True`**, Python skips `slow_function` completely.

You can optimize these expressions by considering the order of the expressions' operators and terms, and order them so that Python evaluates the faster subexpressions first.

Short-Circuiting May Bypass Needed Functions

In the preceding examples, when `slow_function` performs some important "side effect" behavior (such as logging to an audit file, or notifying an administrator of a system condition), short-circuiting may unexpectedly skip that behavior. Take care when including necessary behavior as part of a Boolean expression, and do not overoptimize and remove important functionality.

Short-circuiting of iterators

Similarly to short-circuiting in Boolean expressions, you can short-circuit the evaluation of values in an iterator. Python's built-in functions `all`, `any`, and `next` return after finding the first item in the iterator that meets the given condition, without generating further values:

```
any(x**2 > 100 for x in range(50))
# returns True once it reaches 10, skips the rest

odd_numbers_greater_than_1 = range(3, 100, 2)
all(is_prime(x) for x in odd_numbers_greater_than_1)
# returns False: 3, 5, and 7 are prime but 9 is not

next(c for c in string.ascii_uppercase if c in "AEIOU")
# returns 'A' without checking the remaining characters
```

Your code gains an added advantage when the iterator is specifically a generator, as shown in all three of these cases. When the sequence of items is expensive to produce (as might be the case with records fetched from a database, for example), retrieving those items with a generator and short-circuiting to retrieve only the minimum needed can provide significant performance benefits.

Optimizing loops

Most of your program's bottlenecks will be in loops, particularly nested loops, because loop bodies execute repeatedly. Python does not implicitly perform any *code hoisting*: if you have any code inside a loop that you could execute just once by hoisting it out of the loop, and the loop is a bottleneck, hoist the code out yourself. Sometimes the presence of code to hoist may not be immediately obvious:

```
def slower(anobject, ahugenumber):
    for i in range(ahugenumber):
        anobject.amethod(i)

def faster(anobject, ahugenumber):
    themethod = anobject.amethod
    for i in range(ahugenumber):
        themethod(i)
```

In this case, the code that `faster` hoists out of the loop is the attribute lookup `anobject.amethod`. `slower` repeats the lookup every time, while `faster` performs it just once. The two functions are not 100% equivalent: it is (barely) conceivable that executing `amethod` might cause such changes on `anobject` that the next lookup for the same named attribute fetches a different method object. This is part of why Python doesn't perform such optimizations itself. In practice, such subtle, obscure, and tricky cases happen very rarely; it's almost invariably safe to perform such optimizations yourself, to squeeze the last drop of performance out of some bottleneck.

Python is faster with local variables than with global ones. If a loop repeatedly accesses a global whose value does not change between iterations, you can "cache" the value in a local variable, and access that instead. This also applies to built-ins:

```
def slightly_slower(asequence, adict):
    for x in asequence:
        adict[x] = hex(x)

def slightly_faster(asequence, adict):
    myhex = hex
    for x in asequence:
        adict[x] = myhex(x)
```

Here, the speedup is very modest.

Do not cache **`None`**, **`True`**, or **`False`**. Those constants are keywords: no further optimization is needed.

List comprehensions and generator expressions can be faster than loops, and, sometimes, so can `map` and `filter`. For optimization purposes, try changing loops into list comprehensions, generator expressions, or perhaps `map` and `filter` calls, where feasible. The performance advantage of `map` and `filter` is nullified, and worse, if you have to use a **`lambda`** or an extra level of function call. Only when the argument to `map` or `filter` is a built-in function, or a function you'd have to call anyway even from an explicit loop, list comprehension, or generator expression, do you stand to gain some tiny speedup.

The loops that you can replace most naturally with list comprehensions, or `map` and `filter` calls, are ones that build up a list by repeatedly calling `append` on the list. The following example shows this optimization in a microperformance benchmark script (the example includes a call to the the `timeit` convenience function `repeat`, which simply calls `timeit.timeit` the specified number of times):

```python
import timeit, operator

def slow(asequence):
    result = []
    for x in asequence:
        result.append(-x)
    return result

def middling(asequence):
    return list(map(operator.neg, asequence))

def fast(asequence):
    return [-x for x in asequence]

for afunc in slow, middling, fast:
    timing = timeit.repeat('afunc(big_seq)',
                           setup='big_seq=range(500*1000)',
                           globals={'afunc': afunc},
                           repeat=5,
                           number=100)
    for t in timing:
        print(f'{afunc.__name__},{t}')
```

As we reported in the previous edition of this book (using a different set of test parameters):

> Running this example in v2 on an old laptop shows that `fast` takes about 0.36 seconds, `middling` 0.43 seconds, and `slow` 0.77 seconds. In other words, on that machine, `slow` (the loop of `append` method calls) is about 80 percent slower than `middling` (the single `map` call), and `middling`, in turn, is about 20 percent slower than `fast` (the list comprehension).
>
> The list comprehension is the most direct way to express the task being microbenchmarked in this example, so, not surprisingly, it's also fastest—about two times faster than the loop of `append` method calls.

At that time, using Python 2.7, there was a clear advantage to using the `middling` function over `slow`, and a modest speed increase resulted from using the `fast` function over `middling`. For the versions covered in this edition, the improvement of `fast` over `middling` is much less, if any. Of greater interest is that the `slow` function is now starting to approach the performance of the optimized functions. Also, it is easy to see the progressive performance improvements in successive versions of Python, especially Python 3.11 (see Figure 17-3).

The clear lesson is that performance tuning and optimization measures should be revisited when upgrading to newer Python versions.

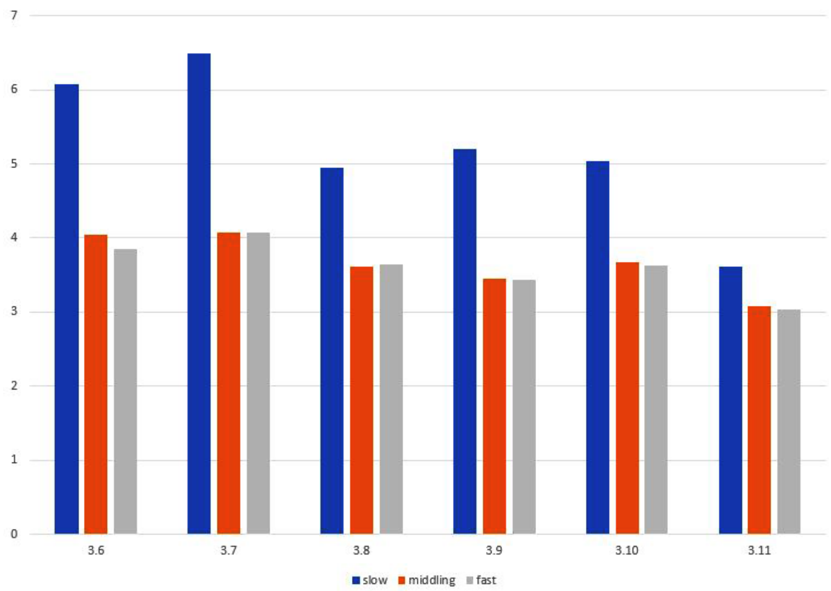


Figure 17-3. Performance of the example on various Python versions

Using multiprocessing for heavy CPU work

If you have heavily CPU-bound processing that can be done in independent pieces, then one important way to optimize is to use multiprocessing, as described in Chapter 15. You should also consider whether using one of the numeric packages described in Chapter 16, capable of applying vector processing to large data sets, is applicable.

Optimizing I/O

If your program does substantial amounts of I/O, it's quite likely that performance bottlenecks are due to I/O, rather than to computation. Such programs are said to be I/O-bound, rather than CPU-bound. Your operating system tries to optimize I/O performance, but you can help it in a couple of ways.

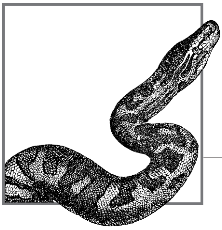
From the point of view of a program's convenience and simplicity, the ideal amount of data to read or write at a time is often small (one character or one line) or very large (an entire file at a time). That's often fine: Python and your operating system work behind the scenes to let your program use convenient logical chunks for I/O, while arranging for physical I/O operations to use chunk sizes more attuned to performance. Reading and writing a whole file at a time is quite likely to be OK for performance as long as the file is not *very* large. Specifically, file-at-a-time I/O is fine as long as the file's data fits very comfortably in physical RAM, leaving ample memory available for your program and operating system to perform whatever other tasks they're doing at the same time. The hard problems of I/O-bound performance come with huge files.

If performance is an issue, *never* use a file's `readline` method, which is limited in the amount of chunking and buffering it can perform. (Using `writelines`, on the other hand, causes no performance problems when that method is convenient for your program.) When reading a text file, loop directly on the file object to get one line at a time with best performance. If the file isn't too huge, and so can conveniently fit in memory, time two versions of your program: one looping directly on the file object, the other reading the whole file into memory. Either may prove faster by a little.

For binary files, particularly large binary files whose contents you need just a part of on each given run of your program, the module `mmap` (covered in "The mmap Module" on page 481) can sometimes help keep your program simple and boost performance.

Making an I/O-bound program multithreaded sometimes affords substantial performance gains, if you can arrange your architecture accordingly. Start a few worker threads devoted to I/O, have the computational threads request I/O operations from the I/O threads via `Queue` instances, and post the request for each input operation as soon as you know you'll eventually need that data. Performance increases only if there are other tasks your computational threads can perform while I/O threads are blocked waiting for data. You get better performance this way only if you can manage to overlap computation and waiting for data by having different threads do the computing and the waiting. (See "Threads in Python" on page 445 for detailed coverage of Python threading and a suggested architecture.)

On the other hand, a possibly even faster and more scalable approach is to eschew threads in favor of asynchronous (event-driven) architectures, as mentioned in Chapter 15.



18 Networking Basics

Connection-oriented protocols work like making a telephone call. You request a connection to a particular *network endpoint* (equivalent to dialing somebody's phone number), and your party either answers or doesn't. If they do, you can talk to them and hear them talking back (simultaneously, if necessary), and you know that nothing is getting lost. At the end of the conversation you both say goodbye and hang up, so it's obvious something has gone wrong if that closing event doesn't occur (for example, if you just suddenly stop hearing the other party). The Transmission Control Protocol (TCP) is the main connection-oriented transport protocol of the internet, used by web browsers, secure shells, email, and many other applications.

Connectionless or *datagram* protocols work more like communicating by sending postcards. Mostly, the messages get through, but if anything goes wrong you have to be prepared to cope with the consequences—the protocol doesn't notify you whether your messages have been received, and messages can arrive out of order. For exchanging short messages and getting answers, datagram protocols have less overhead than connection-oriented ones, as long as the overall service can cope with occasional disruptions. For example, a Domain Name Service (DNS) server may fail to respond: most DNS communication was until recently connectionless. The User Datagram Protocol (UDP) is the main connectionless transport protocol for internet communications.

Nowadays, security is increasingly important: understanding the underlying basis of secure communications helps you ensure that your communications are as secure as they need to be. If this summary dissuades you from trying to implement such technology yourself without a thorough understanding of the issues and risks, it will have served a worthwhile purpose.

All communications across network interfaces exchange strings of bytes. To communicate text, or indeed most other information, the sender must encode it as bytes, which the receiver must decode. We limit our discussion in this chapter to the case of a single sender and a single receiver.

The Berkeley Socket Interface

Most networking nowadays uses *sockets*. Sockets give access to pipelines between independent endpoints, using a *transport layer protocol* to move information between those endpoints. The socket concept is general enough that the endpoints can be on the same computer, or on different computers networked together, either locally or via a wide area network.

The most frequently used transport layers today are UDP (for connectionless networking) and TCP (for connection-oriented networking); each is carried over a common Internet Protocol (IP) network layer. This stack of protocols, along with the many application protocols that run over them, is collectively known as *TCP/IP*. A good introduction is Gordon McMillan's (dated but still perfectly valid) *Socket Programming HOWTO*.

The two most common socket families are *internet sockets* based on TCP/IP communications (available in two flavors, to accommodate the modern IPv6 and the more traditional IPv4) and *Unix sockets*, though other families are also available. Internet sockets allow communication between any two computers that can exchange IP datagrams; Unix sockets can only communicate between processes on the same Unix machine.

To support many concurrent internet sockets, the TCP/IP protocol stack uses endpoints identified by an IP address, a *port number*, and a protocol. The port numbers allow protocol handling software to distinguish between different endpoints at the same IP address using the same protocol. A connected socket is also associated with a *remote endpoint*, the counterparty socket to which it is connected and with which it can communicate.

Most Unix sockets have names in the Unix filesystem. On Linux platforms, sockets whose names begin with a zero byte live in a name pool maintained by the kernel. These are useful for communicating with a chroot-jail process, for example, where no filesystem is shared between two processes.

Both internet and Unix sockets support connectionless and connection-oriented networking, so if you write your programs carefully, they can work over either socket family. It is beyond the scope of this book to discuss other socket families, though we should mention that *raw sockets*, a subtype of the internet socket family, let you send and receive link layer packets (for example, Ethernet packets) directly. This is useful for some experimental applications and for packet sniffing.

After creating an internet socket, you can associate (*bind*) a specific port number with the socket (as long as that port number is not in use by some other socket). This is the strategy many servers use, offering service on so-called *well-known port numbers* defined by internet standards as being in the range 1–1,023. On Unix systems, *root* privileges are required to gain access to these ports. A typical client is unconcerned with the port number it uses, and so it typically requests an *ephemeral port*, assigned by the protocol driver and guaranteed to be unique on that host. There is no need to bind client ports.

Consider two processes on the same computer, each acting as a client to the same remote server. The full association for their sockets has five components, `(local_IP_address, local_port_number, protocol, remote_IP_address, remote_port_number)`. When packets arrive at the remote server, the destination, source IP address, destination port number, and protocol are the same for both clients. The guarantee of uniqueness for ephemeral port numbers lets the server distinguish between traffic from the two clients. This is how TCP/IP handles multiple conversations between the same two IP addresses.[1]

Socket Addresses

The different types of sockets use different address formats:

- Unix socket addresses are strings naming a node in the filesystem (on Linux platforms, bytestrings starting with `b'\0'` and corresponding to names in a kernel table).
- IPv4 socket addresses are `(`*`address, port`*`)` pairs. The first item is an IPv4 address, the second a port number in the range 1–65,535.
- IPv6 socket addresses are four-item `(`*`address, port, flowinfo, scopeid`*`)` tuples. When providing an address as an argument, the *`flowinfo`* and *`scopeid`* items can generally be omitted, as long as the address scope is unimportant.

Client/Server Computing

The pattern we discuss hereafter is usually referred to as *client/server* networking, where a *server* listens for traffic on a specific endpoint from *clients* requiring the service. We do not cover *peer-to-peer* networking, which, lacking any central server, has to include the ability for peers to discover each other.

Most, though by no means all, network communication is performed using client/server techniques. The server listens for incoming traffic at a predetermined or advertised network endpoint. In the absence of such input, it does nothing, simply sitting there waiting for input from clients. Communication is somewhat different between connectionless and connection-oriented endpoints.

In connectionless networking, such as via UDP, requests arrive at a server randomly and are dealt with immediately: a response is dispatched to the requester without delay. Each request is handled on its own, usually without reference to any communications that may previously have occurred between the two parties.

1 When you code an application program, you normally use sockets through higher-abstraction layers, such as those covered in Chapter 19.

Connectionless networking is well suited to short-term, stateless interactions such as those required by DNS or network booting.

In connection-oriented networking, the client engages in an initial exchange with the server that effectively establishes a connection across a network pipeline between two processes (sometimes referred to as a *virtual circuit*), across which the processes can communicate until both indicate their willingness to end the connection. In this case, serving needs to use parallelism (via a concurrency mechanism such as threads, processes, or asynchronicity: see Chapter 15) to handle each incoming connection asynchronously or simultaneously. Without parallelism, the server would be unable to handle new incoming connections before earlier ones have terminated, since calls to socket methods normally *block* (meaning they pause the thread calling them until they terminate or time out). Connections are the best way to handle lengthy interactions such as mail exchanges, command-line shell interactions, or the transmission of web content, and offer automatic error detection and correction when they use TCP.

Connectionless client and server structures

The broad logic flow of a connectionless server proceeds as follows:

1. Create a socket of type `socket.SOCK_DGRAM` by calling `socket.socket`.
2. Associate the socket with the service endpoint by calling the socket's `bind` method.
3. Repeat the following steps *ad infinitum*:
    a. Request an incoming datagram from a client by calling the socket's `recvfrom` method; this call blocks until a datagram is received.
    b. Compute or look up the result.
    c. Send the result back to the client by calling the socket's `sendto` method.

The server spends most of its time in step 3a, awaiting input from clients.

A connectionless client's interaction with the server proceeds as follows:

1. Create a socket of type `socket.SOCK_DGRAM` by calling `socket.socket`.
2. Optionally, associate the socket with a specific endpoint by calling the socket's `bind` method.
3. Send a request to the server's endpoint by calling the socket's `sendto` method.
4. Await the server reply by calling the socket's `recvfrom` method; this call blocks until the response is received. It's necessary to apply a *timeout* to this call, to handle the case where a datagram goes missing and the program must either retry or abort the attempt: connectionless sockets don't guarantee delivery.
5. Use the result in the remainder of the client program's logic.

A single client program can perform several interactions with the same or multiple servers, depending on the services it needs to use. Many such interactions are hidden from the application programmer inside library code. A typical example is the resolution of a hostname to the appropriate network address, which commonly uses the `gethostbyname` library function (implemented in Python's `socket` module, discussed shortly). Connectionless interactions normally involve sending a single packet to the server and receiving a single packet in response. The main exceptions involve *streaming* protocols such as the Real-time Transport Protocol (RTP),[2] which are typically layered on top of UDP to minimize latency and delays: in streaming, many datagrams are sent and received.

Connection-oriented client and server structures

The broad flow of logic of a connection-oriented server is as follows:

1. Create a socket of type `socket.SOCK_STREAM` by calling `socket.socket`.
2. Associate the socket with the appropriate server endpoint by calling the socket's `bind` method.
3. Start the endpoint listening for connection requests by calling the socket's `listen` method.
4. Repeat the following steps *ad infinitum*:
    a. Await an incoming client connection by calling the socket's `accept` method; the server process blocks until an incoming connection request is received. When such a request arrives, a new socket object is created whose other endpoint is the client program.
    b. Create a new control thread or process to handle this specific connection, passing it the newly created socket; the main thread of control then continues by looping back to step 4a.
    c. In the new control thread, interact with the client using the new socket's `recv` and `send` methods, respectively, to read data from the client and send data to it. The `recv` method blocks until data is available from the client (or the client indicates it wishes to close the connection, in which case `recv` returns an empty result). The `send` method only blocks when the network software has so much data buffered that communication has to pause until the transport layer has emptied some of its buffer memory. When the server wishes to close the connection, it can do so by calling the socket's `close` method, optionally calling its `shutdown` method first.

The server spends most of its time in step 4a, awaiting connection requests from clients.

2 And the relatively newfangled multiplexed connections transport protocol QUIC, supported in Python by third-party `aioquic`.

A connection-oriented client's overall logic is as follows:

1. Create a socket of type `socket.SOCK_STREAM` by calling `socket.socket`.
2. Optionally, associate the socket with a specific endpoint by calling the socket's `bind` method.
3. Establish a connection to the server by calling the socket's `connect` method.
4. Interact with the server using the socket's `recv` and `send` methods, respectively, to read data from the server and send data to it. The `recv` method blocks until data is available from the server (or the server indicates it wishes to close the connection, in which case the `recv` call returns an empty result). The `send` method only blocks when the network software has so much data buffered that communications have to pause until the transport layer has emptied some of its buffer memory. When the client wishes to close the connection, it can do so by calling the socket's `close` method, optionally calling its `shutdown` method first.

Connection-oriented interactions tend to be more complex than connectionless ones. Specifically, determining when to read and write data is more complicated, because inputs must be parsed to determine when a transmission from the other end of the socket is complete. The higher-layer protocols used in connection-oriented networking accommodate this determination; sometimes this is done by indicating the data length as a part of the content, sometimes by more sophisticated methods.

The socket Module

Python's `socket` module handles networking with the socket interface. There are minor differences between platforms, but the module hides most of them, making it relatively easy to write portable networking applications.

The module defines three exception classes, all subclasses of the built-in exception class `OSError` (see Table 18-1).

Table 18-1. `socket` module exception classes

`herror`	Identifies hostname resolution errors: e.g., `socket.gethostbyname` cannot convert a name to a network address, or `socket.gethostbyaddr` can find no hostname for a network address. The accompanying value is a two-element tuple (*`h_errno`*, *`string`*), where *`h_errno`* is the integer error number from the operating system, and *`string`* is a description of the error.
`gaierror`	Identifies addressing errors encountered in `socket.getaddrinfo` or `socket.getnameinfo`.
`timeout`	Raised when an operation takes longer than the timeout limit (as per `socket.setdefaulttimeout`, overridable on a per-socket basis).

The module defines many constants. The most important of these are the address families (`AF_*`) and the socket types (`SOCK_*`) listed in Table 18-2, members of

IntEnum collections. The module also defines many other constants used to set socket options, but the documentation does not define them fully: to use them you must be familiar with documentation for the C sockets library and system calls.

Table 18-2. Important constants defined in the `socket` module

AF_BLUETOOTH	Used to create sockets of the Bluetooth address family, used in mobile and Personal Area Network (PAN) applications.
AF_CAN	Used to create sockets for the Controller Area Network (CAN) address family, widely used in automation, automotive, and embedded device applications.
AF_INET	Used to create sockets of the IPv4 address family.
AF_INET6	Used to create sockets of the IPv6 address family.
AF_UNIX	Used to create sockets of the Unix address family. This constant is only defined on platforms that make Unix sockets available.
SOCK_DGRAM	Used to create connectionless sockets, which provide best-effort message delivery without connection capabilities or error detection.
SOCK_RAW	Used to create sockets that give direct access to the link layer drivers; typically used to implement lower-level network features.
SOCK_RDM	Used to create reliable connectionless message sockets used in the Transparent Inter Process Communication (TIPC) protocol.
SOCK_SEQ PACKET	Used to create reliable connection-oriented message sockets used in the TIPC protocol.
SOCK_STREAM	Used to create connection-oriented sockets, which provide full error detection and correction facilities.

The module defines many functions to create sockets, manipulate address information, and assist with standard representations of data. We do not cover all of them in this book, as the socket module's documentation is fairly comprehensive; we deal only with those that are essential in writing networked applications.

The `socket` module contains many functions, most of which are only used in specific situations. For example, when communication takes place between network endpoints, the computers at either end might have architectural differences and represent the same data in different ways, so there are functions to handle translation of a limited number of data types to and from a network-neutral form. Table 18-3 lists a few of the more generally applicable functions this module provides.

Table 18-3. Useful functions of the `socket` module

`getaddrinfo`	`socket.getaddrinfo(`*`host`*`,` *`port`*`, family=0, type=0, proto=0, flags=0)` Takes a *`host`* and *`port`* and returns a list of five-item tuples of the form `(family, type, proto,` *`canonical_name`*`,` *`socket`*`)` usable to create a socket connection to a specific service. *`canonical_name`* is an empty string unless the `socket.AI_CANONNAME` bit is set in the `flags` argument. When you pass a hostname rather than an IP address, `getaddrinfo` returns a list of tuples, one per IP address associated with the name.
`getdefaulttimeout`	`socket.getdefaulttimeout()` Returns the default timeout value in seconds for socket operations, or **None** if no value has been set. Some functions let you specify explicit timeouts.
`getfqdn`	`socket.getfqdn([`*`host`*`])` Returns the fully qualified domain name associated with a hostname or network address (by default, that of the computer on which you call it).
`gethostbyaddr`	`socket.gethostbyaddr(`*`ip_address`*`)` Takes a string containing an IPv4 or IPv6 address and returns a three-item tuple of the form `(`*`hostname`*`,` *`aliaslist`*`,` *`ipaddrlist`*`)`. *`hostname`* is the canonical name for the IP address, *`aliaslist`* is a list of alternative names, and *`ipaddrlist`* is a list of IPv4 and IPv6 addresses.
`gethostbyname`	`socket.gethostbyname(hostname)` Returns a string containing the IPv4 address associated with the given hostname. If called with an IP address, returns that address. This function does not support IPv6: use `getaddrinfo` for IPv6.
`getnameinfo`	`socket.getnameinfo(`*`sock_addr`*`, flags=0)` Takes a socket address and returns a `(`*`host`*`,` *`port`*`)` pair. Without `flags`, *`host`* is an IP address and *`port`* is an `int`.
`setdefaulttimeout`	`socket.setdefaulttimeout(`*`timeout`*`)` Sets sockets' default timeout as a value in floating-point seconds. Newly created sockets operate in the mode determined by the *`timeout`* value, as discussed in the next section. Pass *`timeout`* as **None** to cancel the implicit use of timeouts on subsequently created sockets.

Socket Objects

The socket object is the primary means of network communication in Python. A new socket is also created when a `SOCK_STREAM` socket accepts a connection, each such socket being used to communicate with the relevant client.

Socket Objects and with Statements

Every socket object is a context manager: you can use any socket object in a **`with`** statement to ensure proper termination of the socket at exit from the statement's body. For further details, see "The with Statement and Context Managers" on page 201.

There are several ways to create a socket, as detailed in the next section. Sockets can operate in three different modes, shown in Table 18-4, according to the timeout value, which can be set in different ways:

- By providing the timeout value as an argument on socket creation
- By calling the socket object's `settimeout` method
- According to the `socket` module's default timeout value as returned by the `socket.getdefaulttimeout` function

The timeout values to establish each possible mode are listed in Table 18-4.

Table 18-4. Timeout values and their associated modes

`None`	Sets *blocking* mode. Each operation suspends the thread (*blocks*) until the operation completes, unless the operating system raises an exception.
`0`	Sets *nonblocking* mode. Each operation raises an exception when it cannot be completed immediately, or when an error occurs. Use the `selectors` module to find out whether an operation can be completed immediately.
`>0.0`	Sets *timeout* mode. Each operation blocks until complete, or the timeout elapses (in which case it raises a `socket.timeout` exception), or an error occurs.

Socket objects represent network endpoints. The `socket` module supplies several functions to create a socket (see Table 18-5).

Table 18-5. Socket creation functions

`create_connection`	`create_connection([`*`address`*`[, `*`timeout`*`[, `*`source_address`*`]]])` Creates a socket connected to a TCP endpoint at an address (a `(`*`host`*`, `*`port`*`)` pair). *`host`* can either be a numeric network address or a DNS hostname; in the latter case, name resolution is attempted for both `AF_INET` and `AF_INET6` (in unspecified order), then a connection is attempted to each returned address in turn—a convenient way to create client programs able to use either IPv6 or IPv4. The *`timeout`* argument, if given, specifies the connection timeout in seconds and thereby sets the socket's mode (see Table 18-4); when not present, the `socket.getdefaulttimeout` function is called to determine the value. The *`source_address`* argument, if given, must also be a `(`*`host`*`, `*`port`*`)` pair that the remote socket gets passed as the connecting endpoint. When *`host`* is `''` or *`port`* is `0`, the default OS behavior is used.
`socket`	`socket(family=AF_INET, type=SOCK_STREAM, proto=0, fileno=`**`None`**`)` Creates and returns a socket of the appropriate address family and type (by default, a TCP socket on IPv4). Child processes do not inherit the socket thus created. The protocol number `proto` is only used with CAN sockets. When you pass the `fileno` argument, other arguments are ignored: the function returns the socket already associated with the given file descriptor.

`socketpair`	`socketpair([`*`family`*`[, `*`type`*`[, `*`proto`*`]]])` Returns a connected pair of sockets of the given address family, socket type, and (for CAN sockets only) protocol. When *`family`* is not specified, the sockets are of family `AF_UNIX` on platforms where the family is available; otherwise, they are of family `AF_INET`. When *`type`* is not specified, it defaults to `SOCK_STREAM`.

A socket object *`s`* provides the methods listed in Table 18-6. Those dealing with connections or requiring connected sockets work only for `SOCK_STREAM` sockets, while the others work with both `SOCK_STREAM` and `SOCK_DGRAM` sockets. For methods that take a *`flags`* argument, the exact set of flags available depends on your specific platform (the values available are documented on the Unix manual pages for `recv(2)` and `send(2)` and in the Windows docs); if omitted, *`flags`* defaults to `0`.

Table 18-6. Methods of an instance `s` of `socket`

`accept`	`accept()` Blocks until a client establishes a connection to *`s`*, which must have been bound to an address (with a call to *`s`*`.bind`) and set to listening (with a call to *`s`*`.listen`). Returns a *new* socket object, which can be used to communicate with the other endpoint of the connection.
`bind`	`bind(`*`address`*`)` Binds *`s`* to a specific address. The form of the *`address`* argument depends on the socket's address family (see "Socket Addresses" on page 565).
`close`	`close()` Marks the socket as closed. Calling *`s`*`.close` does not necessarily close the connection immediately, depending on whether other references to the socket exist. If immediate closure is required, call the *`s`*`.shutdown` method first. The simplest way to ensure a socket is closed in a timely fashion is to use it in a **`with`** statement, since sockets are context managers.
`connect`	`connect(`*`address`*`)` Connects to a remote socket at *`address`*. The form of the *`address`* argument depends on the address family (see "Socket Addresses" on page 565).
`detach`	`detach()` Puts the socket into closed mode, but allows the socket object to be reused for further connections (by calling `connect` again).
`dup`	`dup()` Returns a duplicate of the socket, not inheritable by child processes.
`fileno`	`fileno()` Returns the socket's file descriptor.
`getblocking`	`getblocking()` Returns **`True`** if the socket is set to be blocking, either with a call to *`s`*`.setblocking(`**`True`**`)` or *`s`*`.settimeout(`**`None`**`)`. Otherwise, returns **`False`**.

`get_inheritable`	`get_inheritable()` Returns **`True`** when the socket is able to be inherited by child processes. Otherwise, returns **`False`**.
`getpeername`	`getpeername()` Returns the address of the remote endpoint to which this socket is connected.
`getsockname`	`getsockname()` Returns the address being used by this socket.
`gettimeout`	`gettimeout()` Returns the timeout associated with this socket.
`listen`	`listen([`*`backlog`*`])` Starts the socket listening for traffic on its associated endpoint. If given, the integer *`backlog`* argument determines how many unaccepted connections the operating system allows to queue up before starting to refuse connections.
`makefile`	`makefile(`*`mode`*`, buffering=`**`None`**`, *, encoding=`**`None`**`, newline=`**`None`**`)` Returns a file object allowing the socket to be used with file-like operations such as `read` and `write`. The arguments are like those for the built-in `open` function (see "Creating a File Object with open" on page 323). *`mode`* can be `'r'` or `'w'`; `'b'` can be added for binary transmission. The socket must be in blocking mode; if a timeout value is set, unexpected results may be observed if a timeout occurs.
`recv`	`recv(`*`bufsiz`*`[, `*`flags`*`])` Receives and returns a maximum of *`bufsiz`* bytes of data from the socket *`s`*.
`recvfrom`	`recvfrom(`*`bufsiz`*`[, `*`flags`*`])` Receives a maximum of *`bufsiz`* bytes of data from *`s`*. Returns a pair `(`*`bytes`*`, `*`address`*`)`: *`bytes`* is the received data, *`address`* the address of the counterparty socket that sent the data.
`recvfrom_into`	`recvfrom_into(`*`buffer`*`[, `*`nbytes`*`[, `*`flags`*`]])` Receives a maximum of *`nbytes`* bytes of data from *`s`*, writing it into the given *`buffer`* object. If *`nbytes`* is omitted or 0, `len(`*`buffer`*`)` is used. Returns a pair `(`*`nbytes`*`, `*`address`*`)`: *`nbytes`* is the number of bytes received, *`address`* the address of the counterparty socket that sent the data (*_*`into`* functions can be faster than "plain" ones allocating new buffers).
`recv_into`	`recv_into(`*`buffer`*`[, `*`nbytes`*`[, `*`flags`*`]])` Receives a maximum of *`nbytes`* bytes of data from *`s`*, writing it into the given *`buffer`* object. If *`nbytes`* is omitted or `0`, `len(`*`buffer`*`)` is used. Returns the number of bytes received.

`recvmsg`	`recvmsg(`*`bufsiz`*`[,` *`ancbufsiz`*`[,` *`flags`*`]])` Receives a maximum of *`bufsiz`* bytes of data on the socket and a maximum of *`ancbufsiz`* bytes of ancillary ("out-of-band") data. Returns a four-item tuple `(`*`data`*`,` *`ancdata`*`,` *`msg_flags`*`,` *`address`*`)`, where *`bytes`* is the received data, *`ancdata`* is a list of three-item `(`*`cmsg_level`*`,` *`cmsg_type`*`,` *`cmsg_data`*`)` tuples representing the received ancillary data, *`msg_flags`* holds any flags received with the message (documented on the Unix manual page for the `recv(2)` system call or in the Windows docs), and *`address`* is the address of the counterparty socket that sent the data (if the socket is connected, this value is undefined, but the sender can be determined from the socket).
`send`	`send(`*`bytes`*`[,` *`flags`*`])` Sends the given data *`bytes`* over the socket, which must already be connected to a remote endpoint. Returns the number of bytes sent, which you should check: the call may not transmit all data, in which case transmission of the remainder will have to be separately requested.
`sendall`	`sendall(`*`bytes`*`[,` *`flags`*`])` Sends all the given data *`bytes`* over the socket, which must already be connected to a remote endpoint. The socket's timeout value applies to the transmission of all the data, even if multiple transmissions are needed.
`sendfile`	`sendfile(`*`file`*`, offset=0, count=`**`None`**`)` Send the contents of file object *`file`* (which must be open in binary mode) to the connected endpoint. On platforms where `os.sendfile` is available, it's used; otherwise, the `send` call is used. `offset`, if any, determines the starting byte position in the file from which transmission begins; `count` sets the maximum number of bytes to transmit. Returns the total number of bytes transmitted.
`sendmsg`	`sendmsg(`*`buffers`*`[,` *`ancdata`*`[,` *`flags`*`[,` *`address`*`]]])` Sends normal and ancillary (out-of-band) data to the connected endpoint. *`buffers`* should be an iterable of bytes-like objects. The *`ancdata`* argument should be an iterable of `(`*`data`*`,` *`ancdata`*`,` *`msg_flags`*`,` *`address`*`)` tuples representing the ancillary data. *`msg_flags`* are flags documented on the Unix manual page for the `send(2)` system call or in the Windows docs. *`address`* should only be provided for an unconnected socket, and determines the endpoint to which the data is sent.
`sendto`	`sendto(`*`bytes`*`,[`*`flags`*`,]`*`address`*`)` Transmits the *`bytes`* (*`s`* must not be connected) to the given socket address, and returns the number of bytes sent. The optional *`flags`* argument has the same meaning as for `recv`.
`setblocking`	`setblocking(`*`flag`*`)` Determines whether *`s`* operates in blocking mode (see "Socket Objects" on page 570), according to the truth value of *`flag`*. *`s`*`.setblocking(`**`True`**`)` works like *`s`*`.settimeout(`**`None`**`)`; *`s`*`.set_blocking(`**`False`**`)` works like *`s`*`.settimeout(0.0)`.
`set_inheritable`	`set_inheritable(`*`flag`*`)` Determines whether the socket gets inherited by child processes, according to the truth value of *`flag`*.

`settimeout`	`settimeout(timeout)` Establishes the mode of *s* (see "Socket Objects" on page 570) according to the value of *timeout*.

`shutdown`	`shutdown(how)`
	Shuts down one or both halves of a socket connection according to the value of the *how* argument, as detailed here:
	
	`socket.SHUT_RD`
	No further receive operations can be performed on *s*.
	
	`socket.SHUT_RDWR`
	No further receive or send operations can be performed on *s*.
	
	`socket.SHUT_WR`
	No further send operations can be performed on *s*.

A socket object *s* also has the attributes `family` (*s*'s socket family) and `type` (*s*'s socket type).

A Connectionless Socket Client

Consider a simplistic packet-echo service, where a client sends text encoded in UTF-8 to a server, which sends the same information back to the client. In a connectionless service, all the client has to do is send each chunk of data to the defined server endpoint:

```
import socket

UDP_IP = 'localhost'
UDP_PORT = 8883
MESSAGE = """\
This is a bunch of lines, each
of which will be sent in a single
UDP datagram. No error detection
or correction will occur.
Crazy bananas! £€ should go through."""

server = UDP_IP, UDP_PORT
encoding = 'utf-8'
with socket.socket(socket.AF_INET,     # IPv4
                   socket.SOCK_DGRAM, # UDP
                  ) as sock:
    for line in MESSAGE.splitlines():
        data = line.encode(encoding)
        bytes_sent = sock.sendto(data, server)
        print(f'SENT {data!r} ({bytes_sent} of {len(data)})'
              f' to {server}')
        response, address = sock.recvfrom(1024)  # buffer size: 1024
        print(f'RCVD {response.decode(encoding)!r}'
              f' from {address}')
```

```
    print('Disconnected from server')
```

Note that the server only performs a bytes-oriented echo function. The client, therefore, encodes its Unicode data into bytestrings, and decodes the bytestring responses received from the server back into Unicode text using the same encoding.

A Connectionless Socket Server

A server for the packet-echo service described in the previous section is also quite simple. It binds to its endpoint, receives packets (datagrams) at that endpoint, and returns to the client sending each datagram a packet with exactly the same data. The server treats all clients equally and does not need to use any kind of concurrency (though this last handy characteristic might not hold for a service where request handling takes more time).

The following server works, but offers no way to terminate the service other than by interrupting it (typically from the keyboard, with Ctrl-C or Ctrl-Break):

```
import socket

UDP_IP = 'localhost'
UDP_PORT = 8883
with socket.socket(socket.AF_INET,     # IPv4
                   socket.SOCK_DGRAM   # UDP
                   ) as sock:
    sock.bind((UDP_IP, UDP_PORT))
    print(f'Serving at {UDP_IP}:{UDP_PORT}')
    while True:
        data, sender_addr = sock.recvfrom(1024)  # 1024-byte buffer
        print(f'RCVD {data!r}) from {sender_addr}')
        bytes_sent = sock.sendto(data, sender_addr)
        print(f'SENT {data!r} ({bytes_sent}/{len(data)})'
              f' to {sender_addr}')
```

Neither is there any mechanism to handle dropped packets and similar network problems; this is often acceptable in simple services.

You can run the same programs using IPv6: simply replace the socket type `AF_INET` with `AF_INET6`.

A Connection-Oriented Socket Client

Now consider a simplistic connection-oriented "echo-like" protocol: a server lets clients connect to its listening socket, receives arbitrary bytes from them, and sends back to each client the same bytes that client sent to the server, until the client closes the connection. Here's an example of an elementary test client:[3]

```
import socket

IP_ADDR = 'localhost'
IP_PORT = 8881
MESSAGE = """\
A few lines of text
including non-ASCII characters: €£
to test the operation
of both server
and client."""

encoding = 'utf-8'
with socket.socket(socket.AF_INET,      # IPv4
                   socket.SOCK_STREAM   # TCP
                   ) as sock:
    sock.connect((IP_ADDR, IP_PORT))
    print(f'Connected to server {IP_ADDR}:{IP_PORT}')
    for line in MESSAGE.splitlines():
        data = line.encode(encoding)
        sock.sendall(data)
        print(f'SENT {data!r} ({len(data)})')
        response, address = sock.recvfrom(1024)  # buffer size: 1024
        print(f'RCVD {response.decode(encoding)!r}'
              f' ({len(response)}) from {address}')

print('Disconnected from server')
```

Note that the data is text, so it must be encoded with a suitable representation. We chose the usual suspect, UTF-8. The server works in terms of bytes (since it is bytes, aka octets, that travel on the network); the received bytes object gets decoded with UTF-8 back into Unicode text before printing. Any other suitable codec could be used instead: the key point is that text must be encoded before transmission and decoded after reception. The server, working in terms of bytes, does not even need to know which encoding is being used, except maybe for logging purposes.

3 This client example isn't secure; see "Transport Layer Security" on page 579 for an introduction to making it secure.

A Connection-Oriented Socket Server

Here is a simplistic server corresponding to the testing client shown in the previous section, using multithreading via `concurrent.futures` (covered in "The concurrent.futures Module" on page 468):

```
import concurrent
import socket

IP_ADDR = 'localhost'
IP_PORT = 8881

def handle(new_sock, address):
    print('Connected from', address)
    with new_sock:
        while True:
            received = new_sock.recv(1024)
            if not received:
                break
            s = received.decode('utf-8', errors='replace')
            print(f'Recv: {s!r}')
            new_sock.sendall(received)
            print(f'Echo: {s!r}')
    print(f'Disconnected from {address}')

with socket.socket(socket.AF_INET,     # IPv4
                   socket.SOCK_STREAM  # TCP
                   ) as servsock:
    servsock.bind((IP_ADDR, IP_PORT))
    servsock.listen(5)
    print(f'Serving at {servsock.getsockname()}')
    with cconcurrent.futures.ThreadPoolExecutor(20) as e:
        while True:
            new_sock, address = servsock.accept()
            e.submit(handle, new_sock, address)
```

This server has its limits. In particular, it runs only 20 threads, so it cannot simultaneously serve more than 20 clients; any further client trying to connect while 20 others are already being served waits in `servsock`'s listening queue. Should that queue fill up with five clients waiting to be accepted, further clients attempting connection get rejected outright. This server is intended just as an elementary example for demonstration purposes, not as a solid, scalable, or secure system.

As before, the same programs can be run using IPv6 by replacing the socket type `AF_INET` with `AF_INET6`.

Transport Layer Security

Transport Layer Security (TLS), the successor of Secure Sockets Layer (SSL), provides privacy and data integrity over TCP/IP, helping you defend against server impersonation, eavesdropping on the bytes being exchanged, and malicious alteration of those bytes. For an introduction to TLS, we recommend the extensive Wikipedia entry.

In Python, you can use TLS via the `ssl` module of the standard library. To use `ssl` well, you need a good grasp of its rich online docs, as well as a deep and broad understanding of TLS itself (the Wikipedia article, excellent and vast as it is, can only begin to cover this large, difficult subject). In particular, you must study and thoroughly understand the security considerations section of the online docs, as well as all the materials found at the many links helpfully offered in that section.

If these warnings make it sound as though a perfect implementation of security precautions is a daunting task, that's because it *is*. In security, you're pitting your wits and skills against those of sophisticated attackers who may be more familiar with the nooks and crannies of the problems involved: they specialize in finding workarounds and breaking in, while (usually) your focus is not exclusively on such issues—rather, you're trying to provide some useful services in your code. It's risky to see security as an afterthought or a secondary point—it *has* to be front and center throughout, to win said battle of skills and wits.

That said, we strongly recommend that all readers undertake the study of TLS mentioned above—the better all developers understand security considerations, the better off we all are (except, we guess, the security-breaker wannabes!).

Unless you have acquired a really deep and broad understanding of TLS and Python's `ssl` module (in which case, you'll know what exactly to do—better than we possibly could!), we recommend using an `SSLContext` instance to hold all the details of your use of TLS. Build that instance with the `ssl.create_default_context` function, add your certificate if needed (it *is* needed if you're writing a secure server), then use the instance's `wrap_socket` method to wrap (almost[4]) every `socket.socket` instance you make into an instance of `ssl.SSLSocket`—behaving almost identically to the socket object it wraps, but nearly transparently adding security checks and validation "on the side."

The default TLS contexts strike a good compromise between security and broad usability, and we recommend you stick with them (unless you're knowledgeable enough to fine-tune and tighten security for special needs). If you need to support outdated counterparts that are unable to use the most recent, most secure implementations of TLS, you may feel tempted to learn just enough to relax your

4 We say "almost" because, when you code a server, you don't wrap the socket you bind, listen on, and accept connections from.

security demands. Do that at your own risk—we most definitely *don't* recommend wandering into such territory!

In the following sections, we cover the minimal subset of ssl you need to be familiar with if you just want to follow our recommendations. But even if that is the case, *please* also read up on TLS and ssl, just to gain some background knowledge about the intricate issues involved. It may stand you in good stead one day!

SSLContext

The ssl module supplies an ssl.SSLContext class, whose instances hold information about TLS configuration (including certificates and private keys) and offer many methods to set, change, check, and use that information. If you know exactly what you're doing, you can manually instantiate, set up, and use your own SSLContext instances for your own specialized purposes.

However, we recommend instead that you instantiate an SSLContext using the well-tuned function ssl.create_default_context, with a single argument: ssl.Purpose.CLIENT_AUTH if your code is a server (and thus may need to authenticate clients), or ssl.Purpose.SERVER_AUTH if your code is a client (and thus definitely needs to authenticate servers). If your code is both a client to some servers and a server to other clients (as, for example, some internet proxies are), then you'll need two instances of SSLContext, one for each purpose.

For most client-side uses, your SSLContext is ready. If you're coding a server, or a client for one of the rare servers that require TLS authentication of the clients, you need to have a certificate file and a key file (see the online docs to learn how to obtain these files). Add them to the SSLContext instance (so that counterparties can verify your identity) by passing the paths to the certificate and key files to the load_cert_chain method with code like the following:

```
ctx = ssl.create_default_context(ssl.Purpose.CLIENT_AUTH)
ctx.load_cert_chain(certfile='mycert.pem', keyfile='mykey.key')
```

Once your context instance *ctx* is ready, if you're coding a client, just call *ctx*.wrap_socket to wrap any socket you're about to connect to a server, and use the wrapped result (an instance of ssl.SSLSocket) instead of the socket you just wrapped. For example:

```
sock = socket.socket(socket.AF_INET)
sock = ctx.wrap_socket(sock, server_hostname='www.example.com')
sock.connect(('www.example.com', 443))
# use 'sock' normally from here on
```

Note that, in the client case, you should also pass wrap_socket a server_hostname argument corresponding to the server you're about to connect to; this way, the connection can verify that the identity of the server you end up connecting to is indeed correct, an absolutely crucial security step.

Server-side, *don't* wrap the socket that you are binding to an address, listening on, or accepting connections on; just wrap the new socket that `accept` returns. For example:

```
sock = socket.socket(socket.AF_INET)
sock.bind(('www.example.com', 443))
sock.listen(5)
while True:
    newsock, fromaddr = sock.accept()
    newsock = ctx.wrap_socket(newsock, server_side=True)
    # deal with 'newsock' as usual; shut down, then close it, when done
```

In this case, you need to pass `wrap_socket` the argument `server_side=True` so it knows that you're on the server side of things.

Again, we recommend consulting the online docs—particularly the examples—for better understanding, even if you stick to just this simple subset of `ssl` operations.

19 Client-Side Network Protocol Modules

Python's standard library supplies several modules to simplify the use of internet protocols on both the client and server sides. These days, the Python Package Index, best known as *PyPI*, offers many more such packages. Because many of the standard library modules date back to the previous century, you will find that nowadays third-party packages support a wider array of protocols, and several offer better APIs than the standard library's equivalents. When you need to use a network protocol that's missing from the standard library, or covered by the standard library in a way you think is not satisfactory, be sure to search PyPI—you're likely to find better solutions there.

In this chapter, we cover some standard library packages that allow relatively simple uses of network protocols: these let you code without requiring third-party packages, making your application or library easier to install on other machines. You may therefore come across them when dealing with legacy code, and their simplicity also makes them interesting reading for the Python student. We also mention a few third-party packages covering important network protocols not included in the standard library, but we do not cover third-party packages using asynchronous programming.

For the very frequent use case of HTTP clients and other network resources (such as anonymous FTP sites) best accessed via URLs, the third-party `requests` package is even recommended in the Python documentation, so we cover that and recommend its use instead of standard library modules.

Email Protocols

Most email today is *sent* via servers implementing the Simple Mail Transport Protocol (SMTP) and *received* via servers and clients using Post Office Protocol version 3 (POP3) and/or Internet Message Access Protocol version 4 (IMAP4).[1] Clients for these protocols are supported by the Python standard library modules `smtplib`, `poplib`, and `imaplib`, respectively, the first two of which we cover in this book. When you need to handle *parsing* or *generating* email messages, use the `email` package, covered in Chapter 21.

If you need to write a client that can connect via either POP3 or IMAP4, a standard recommendation would be to pick IMAP4, since it is more powerful and—according to Python's own online docs—often more accurately implemented on the server side. Unfortunately, `imaplib` is very complex, and far too vast to cover in this book. If you do choose to go that route, use the online docs, inevitably complemented by the IMAP RFCs, and possibly other related RFCs, such as 5161 and 6855 for capabilities and 2342 for namespaces. Using the RFCs in addition to the online docs for the standard library module can't be avoided: many of the arguments passed to `imaplib` functions and methods, and results from calling them, are strings with formats that are only documented in the RFCs, not in Python's own docs. A highly recommended alternative is to use the simpler, higher-abstraction-level third-party package IMAPClient, available with a **`pip install`** and well documented online.

The poplib Module

The `poplib` module supplies a class, `POP3`, to access a POP mailbox.[2] The constructor has the following signature:

POP3 **`class`** `POP3(`*`host`*`, port=110)`

Returns an instance *p* of class `POP3` connected to the specified *`host`* and `port`. The class `POP3_SSL` behaves just the same, but connects to the host (by default on port 995) over a secure TLS channel; it's needed to connect to email servers that demand some minimum security, such as `pop.gmail.com`.[a]

[a] To connect to a Gmail account, in particular, you need to configure that account to enable POP, "allow less secure apps," and avoid two-step verification—things that in general we don't recommend, as they weaken your email's security.

An instance *p* of the class `POP3` supplies many methods; the most frequently used are listed in Table 19-1. In each case, *`msgnum`*, the identifying number of a message, can be a string containing an integer value or an `int`.

1 IMAP4, per RFC 1730; or IMAP4rev1, per RFC 2060.

2 The specification of the POP protocol can be found in RFC 1939.

Table 19-1. Methods of an instance p of POP3

dele	*p*.dele(*msgnum*) Marks message *msgnum* for deletion and returns the server response string. The server queues such deletion requests, and executes them only when you terminate this connection by calling *p*.quit.[a]
list	*p*.list(*msgnum*=**None**) Returns a three-item tuple (*response*, *messages*, *octets*), where *response* is the server response string; *messages* a list of bytestrings, each of two words b'*msgnum bytes*', the message number and length, in bytes, of each message in the mailbox; and *octets* is the length, in bytes, of the total response. When *msgnum* is not **None**, list returns a string, the response for the given *msgnum*, not a tuple.
pass_	*p*.pass_(*password*) Sends the password to the server, and returns the server response string. Must be called after *p*.user. The trailing underscore in the name is needed because **pass** is a Python keyword.
quit	*p*.quit() Ends the session and tells the server to perform deletions that were requested by calls to *p*.dele. Returns the server response string.
retr	*p*.retr(*msgnum*) Returns a three-item tuple (*response*, *lines*, *bytes*), where *response* is the server response string, *lines* is the list of all lines in message *msgnum* as bytestrings, and *bytes* is the total number of bytes in the message.
set_debuglevel	*p*.set_debuglevel(*debug_level*) Sets the debug level to *debug_level*, an int with value 0 (the default) for no debugging, 1 for a modest amount of debugging output, or 2 or more for a complete output trace of all control information exchanged with the server.
stat	*p*.stat() Returns a pair (*num_msgs*, *bytes*), where *num_msgs* is the number of messages in the mailbox and *bytes* is the total number of bytes.
top	*p*.top(*msgnum*, *maxlines*) Like retr, but returns at most *maxlines* lines from the message's body (in addition to all the lines from the headers). Can be useful for peeking at the start of long messages.
user	*p*.user(*username*) Sends the server the username; invariably followed up by a call to *p*.pass_.

[a] The standard states that if disconnection occurs before the quit call, the deletions should not be actioned. Despite this, some servers will perform the deletion after any disconnection, planned or unplanned.

The smtplib Module

The `smtplib` module supplies a class, `SMTP`, to send mail via an SMTP server.[3] The constructor has the following signature:

SMTP	`class SMTP([host, port=25])` Returns an instance *s* of the class `SMTP`. When *host* (and optionally `port`) is given, implicitly calls `s.connect(host, port)`. The class `SMTP_SSL` behaves just the same, but connects to the host (by default on port 465) over a secure TLS channel; it's needed to connect to email servers that demand some minimum security, such as `smtp.gmail.com`.

An instance *s* of the class `SMTP` supplies many methods. The most frequently used of these are listed in Table 19-2.

Table 19-2. Methods of an instance s of SMTP

connect	`s.connect(host=127.0.0.1, port=25)` Connects to an SMTP server on the given `host` (by default, the local host) and `port` (port `25` is the default port for the SMTP service; `465` is the default port for the more secure "SMTP over TLS").
login	`s.login(user, password)` Logs in to the server with the given *user* and *password*. Needed only if the SMTP server requires authentication (as just about all do).
quit	`s.quit()` Terminates the SMTP session.
sendmail	`s.sendmail(from_addr, to_addrs, msg_string)` Sends mail message *msg_string* from the sender whose address is in string *from_addr* to each of the recipients in the list *to_addrs*.[a] *msg_string* must be a complete RFC 822 message in a single multiline bytestring: the headers, an empty line for separation, then the body. The mail transport mechanism uses only *from_addr* and *to_addrs* to determine routing, ignoring any headers in *msg_string*.[b] To prepare RFC 822–compliant messages, use the package `email`, covered in "MIME and Email Format Handling" on page 611.
send_message	`s.send_message(msg, from_addr=None, to_addrs=None)` A convenience function taking an `email.message.Message` object as its first argument. If either or both of `from_addr` and `to_addrs` are **None**, they are extracted from the message instead.

[a] While the standard places no limits on the number of recipients in *from_addr*, individual mail servers may well do so, often making it advisable to batch messages with a maximum number of recipients in each one.

[b] This allows email systems to implement Bcc (blind copy) emails, for example, as the routing does not depend on the message envelope.

3 The specification of the SMTP protocol can be found in RFC 2821.

HTTP and URL Clients

Most of the time, your code uses the HTTP and FTP protocols through the higher-abstraction URL layer, supported by the modules and packages covered in the following sections. Python's standard library also offers lower-level, protocol-specific modules that are less often used: for FTP clients, ftplib; for HTTP clients, `http.client` (we cover HTTP servers in Chapter 20). If you need to write an FTP server, look at the third-party module pyftpdlib. Implementations of the newer HTTP/2 may not be fully mature, but your best bet as of this writing is the third-party module HTTPX. We do not cover any of these lower-level modules in this book: we focus on higher-abstraction, URL-level access throughout the following sections.

URL Access

A URL is a type of uniform resource identifier (URI). A URI is a string that *identifies* a resource (but does not necessarily *locate* it), while a URL *locates* a resource on the internet. A URL is a string composed of several parts (some optional), called *components*: the *scheme, location, path, query*, and *fragment*. (The second component is sometimes also known as a *net location*, or *netloc* for short.) A URL with all parts looks like:

```
scheme://lo.ca.ti.on/pa/th?qu=ery#fragment
```

In *https://www.python.org/community/awards/psf-awards/#october-2016*, for example, the scheme is *http*, the location is *www.python.org*, the path is */community/awards/psf-awards/*, there is no query, and the fragment is *#october-2016*. (Most schemes default to a *well-known port* when the port is not explicitly specified; for example, 80 is the well-known port for the HTTP scheme.) Some punctuation is part of one of the components it separates; other punctuation characters are just separators, not part of any component. Omitting punctuation implies missing components. For example, in *mailto:me@you.com*, the scheme is *mailto*, the path is *me@you.com* (*mailto:me@you.com*), and there is no location, query, or fragment. No // means the URI has no location, no `?` means it has no query, and no `#` means it has no fragment.

If the location ends with a colon followed by a number, this denotes a TCP port for the endpoint. Otherwise, the connection uses the well-known port associated with the scheme (e.g., port 80 for HTTP).

The urllib Package

The `urllib` package supplies several modules for parsing and utilizing URL strings and associated resources. In addition to the `urllib.parse` and `urllib.request` modules described here, these include the module `urllib.robotparser` (for the specific purpose of parsing a site's *robots.txt* file as per RFC 9309) and the module `urllib.error`, containing all exception types raised by other `urllib` modules.

The urllib.parse module

The `urllib.parse` module supplies functions for analyzing and synthesizing URL strings, and is typically imported with **`from`** `urllib` **`import`** `parse` **`as`** `urlparse`. Its most frequently used functions are listed in Table 19-3.

Table 19-3. Useful functions of the `urllib.parse` module

`urljoin`

`urljoin(`*`base_url_string`*`, `*`relative_url_string`*`)`

Returns a URL string *u*, obtained by joining *`relative_url_string`*, which may be relative, with *`base_url_string`*. The joining procedure that `urljoin` performs to obtain its result may be summarized as follows:

- When either of the argument strings is empty, *u* is the other argument.
- When *`relative_url_string`* explicitly specifies a scheme that is different from that of *`base_url_string`*, *u* is *`relative_url_string`*. Otherwise, *u*'s scheme is that of *`base_url_string`*.
- When the scheme does not allow relative URLs (e.g., `mailto`), or when *`relative_url_string`* explicitly specifies a location (even when it is the same as the location of *`base_url_string`*), all other components of *u* are those of *`relative_url_string`*. Otherwise, *u*'s location is that of *`base_url_string`*.
- *u*'s path is obtained by joining the paths of *`base_url_string`* and *`relative_url_string`* according to standard syntax for absolute and relative URL paths.[a] For example:

```
urlparse.urljoin(
  'http://host.com/some/path/here','../other/path')
# Result is: 'http://host.com/some/other/path'
```

`urlsplit`	`urlsplit(`*`url_string`*`, default_scheme='', allow_fragments=`**`True`**`)`
	Analyzes *`url_string`* and returns a tuple (actually an instance of `SplitResult`, which you can treat as a tuple or use with named attributes) with five string items: *`scheme`*, *`netloc`*, *`path`*, *`query`*, and *`fragment`*. *`default_scheme`* is the first item when the *`url_string`* lacks an explicit scheme. When `allow_fragments` is **`False`**, the tuple's last item is always `''`, whether or not *`url_string`* has a fragment. Items corresponding to missing parts are also `''`. For example:
	`urlparse.urlsplit(`
	`  'http://www.python.org:80/faq.cgi?src=file')`
	`# Result is:`
	`# 'http','www.python.org:80','/faq.cgi','src=file',''`

`urlunsplit`	`urlunsplit(`*`url_tuple`*`)`
	`url_tuple` is any iterable with exactly five items, all strings. Any return value from a `urlsplit` call is an acceptable argument for `urlunsplit`. `urlunsplit` returns a URL string with the given components and the needed separators, but with no redundant separators (e.g., there is no # in the result when the fragment, *`url_tuple`*'s last item, is `''`). For example:
	`urlparse.urlunsplit((`
	`  'http','www.python.org','/faq.cgi','src=fie',''))`
	`# Result is: 'http://www.python.org/faq.cgi?src=fie'`
	`urlunsplit(urlsplit(`*`x`*`))` returns a normalized form of URL string *x*, which is not necessarily equal to *x* because *x* need not be normalized. For example:
	`urlparse.urlsplit('http://a.com/path/a?'))`
	`# Result is: 'http://a.com/path/a'`
	In this case, the normalization ensures that redundant separators, such as the trailing `?` in the argument to `urlsplit`, are not present in the result.

[a] Per RFC 1808.

The urllib.request module

The `urllib.request` module supplies functions for accessing data resources over standard internet protocols, the most commonly used of which are listed in Table 19-4. (The examples in the table assume you've imported the module.)

Table 19-4. Useful functions of the `urllib.request` module

<table>
<tr>
<td><code>urlopen</code></td>
<td><code>urlopen(url, data=None, timeout, context=None)</code>
Returns a response object whose type depends on the scheme in <code>url</code>:

HTTP and HTTPS URLs return an <code>http.client.HTTPResponse</code> object (with the <code>msg</code> attribute modified to contain the same data as the <code>reason</code> attribute; for details, see the online docs). Your code can use this object like an iterable, and as a context manager in a <code>with</code> statement.
FTP, file, and data URLs return a <code>urllib.response.addinfourl</code> object.

<code>url</code> is the string or <code>urllib.request.Request</code> object for the URL to open. <code>data</code> is an optional <code>bytes</code> object, file-like object, or iterable of bytes, encoding additional data to send to the URL following <code>application/x-www-form-urlencoded</code> format. <code>timeout</code> is an optional argument for specifying, in seconds, a timeout for blocking operations of the URL opening process, applicable only for HTTP, HTTPS, and FTP URLs. When <code>context</code> is given, it must contain an <code>ssl.SSLContext</code> object specifying SSL options; <code>context</code> replaces the deprecated <code>cafile</code>, <code>capath</code>, and <code>cadefault</code> arguments. The following example downloads a file from an HTTPS URL and extracts it into a local <code>bytes</code> object, <code>unicode_db</code>:
<pre><code>unicode_url = ("https://www.unicode.org/Public"
               "/14.0.0/ucd/UnicodeData.txt")
with urllib.request.urlopen(unicode_url
)as url_response:
    unicode_db = url_response.read()
</code></pre>
</td>
</tr>
<tr>
<td><code>url
retrieve</code></td>
<td><code>urlretrieve(url_string, filename=None, report_hook=None, data=None)</code>
A compatibility function to support migration from Python 2 legacy code. <code>url_string</code> gives the URL of the resource to download. <code>filename</code> is an optional string naming the local file in which to store the data retrieved from the URL. <code>report_hook</code> is a callable to support progress reporting during downloading, called once as each block of data is retrieved. <code>data</code> is similar to the <code>data</code> argument for <code>urlopen</code>. In its simplest form, <code>urlretrieve</code> is equivalent to:
<pre><code>def urlretrieve(url, filename=None):
    if filename is None:
        filename = ...parse filename from url...
    with urllib.request.urlopen(url
)as url_response:
        with open(filename, "wb") as save_file:
            save_file.write(url_response.read())
        return filename, url_response.info()
</code></pre>
Since this function was developed for Python 2 compatibility, you may still see it in existing codebases. New code should use <code>urlopen</code>.</td>
</tr>
</table>

For full coverage of `urllib.request` see the online docs and Michael Foord's HOWTO, which includes examples on downloading files given a URL. There's a short example using `urllib.request` in "An HTML Parsing Example with BeautifulSoup" on page 635.

The Third-Party requests Package

The third-party `requests` package (very well documented online) is how we recommend you access HTTP URLs. As usual for third-party packages, it's best installed with a simple **`pip install requests`**. In this section, we summarize how best to use it for reasonably simple cases.

Natively, `requests` only supports the HTTP and HTTPS transport protocols; to access URLs using other protocols, you need to install other third-party packages (known as *protocol adapters*), such as requests-ftp for FTP URLs, or others supplied as part of the rich requests-toolbelt package of `requests` utilities.

The `requests` package's functionality hinges mostly on three classes it supplies: `Request`, modeling an HTTP request to be sent to a server; `Response`, modeling a server's HTTP response to a request; and `Session`, offering continuity across a sequence of requests, also known as a *session*. For the common use case of a single request/response interaction, you don't need continuity, so you may often just ignore `Session`.

Sending requests

Typically, you don't need to explicitly consider the `Request` class: rather, you call the utility function `request`, which internally prepares and sends the `Request` and returns the `Response` instance. `request` has two mandatory positional arguments, both `str`s: `method`, the HTTP method to use, and `url`, the URL to address. Then, many optional named parameters may follow (in the next section, we cover the most commonly used named parameters to the `request` function).

For further convenience, the `requests` module also supplies functions whose names are those of the HTTP methods `delete`, `get`, `head`, `options`, `patch`, `post`, and `put`; each takes a single mandatory positional argument, `url`, then the same optional named arguments as the function `request`.

When you want some continuity across multiple requests, call `Session` to make an instance *`s`*, then use *`s`*'s methods `request`, `get`, `post`, and so on, which are just like the functions with the same names directly supplied by the `requests` module (however, *`s`*'s methods merge *`s`*'s settings with the optional named parameters to prepare each request to send to the given `url`).

request's optional named parameters

The function `request` (just like the functions `get`, `post`, and so on, and methods with the same names on an instance *`s`* of class `Session`) accepts many optional named parameters. Refer to the `requests` package's excellent online docs for the full set if you need advanced functionality such as control over proxies, authentication, special treatment of redirection, streaming, cookies, and so on. Table 19-5 lists the most frequently used named parameters.

Table 19-5. Named parameters accepted by the `request` function

`data`	A `dict`, a sequence of key/value pairs, a bytestring, or a file-like object to use as the body of the request
`files`	A `dict` with names as keys and file-like objects or *file tuples* as values, used with the POST method to specify a multipart-encoding file upload (we cover the format of values for `files` in the next section)
`headers`	A `dict` of HTTP headers to send in the request
`json`	Python data (usually a `dict`) to encode as JSON as the body of the request
`params`	A `dict` of (*`name, value`*) items, or a bytestring to send as the query string with the request
`timeout`	A `float` number of seconds, the maximum time to wait for the response before raising an exception

`data`, `json`, and `files` are mutually incompatible ways to specify a body for the request; you should normally use at most one of them, and only for HTTP methods that do use a body (namely PATCH, POST, and PUT). The one exception is that you can have both a `data` argument passing a `dict` and a `files` argument. That is very common usage: in this case, both the key/value pairs in the `dict` and the files form the body of the request as a single *multipart/form-data* whole.[4]

The files argument (and other ways to specify the request's body)

When you specify the request's body with `json` or `data` (passing a bytestring or a file-like object, which must be open for reading, usually in binary mode), the resulting bytes are directly used as the request's body. When you specify it with `data` (passing a `dict` or a sequence of key/value pairs), the body is built as a *form*, from the key/value pairs formatted in *application/x-www-form-urlencoded* format, according to the relevant web standard.

When you specify the request's body with `files`, the body is also built as a form, in this case with the format set to *multipart/form-data* (the only way to upload files in a PATCH, POST, or PUT HTTP request). Each file you're uploading is formatted into its own part of the form; if, in addition, you want the form to give to the server further nonfile parameters, then in addition to `files`, you need to pass a `data` argument with a `dict` value (or a sequence of key/value pairs) for the further parameters. Those parameters get encoded into a supplementary part of the multipart form.

For flexibility, the value of the `files` argument can be a `dict` (its items are taken as a sequence of (*`name, value`*) pairs), or a sequence of (*`name, value`*) pairs (order is maintained in the resulting request body).

4 According to RFC 2388.

Either way, each value in a (*name*, *value*) pair can be a `str` (or, better,[5] a `bytes` or `bytearray`) to be used directly as the uploaded file's contents, or a file-like object open for reading (then, `requests` calls `.read()` on it and uses the result as the uploaded file's contents; we strongly urge that in such cases you open the file in binary mode to avoid any ambiguity regarding content length). When any of these conditions apply, `requests` uses the *name* part of the pair (e.g., the key into the `dict`) as the file's name (unless it can improve on that because the open file object is able to reveal its underlying filename), takes its best guess at a content type, and uses minimal headers for the file's form part.

Alternatively, the value in each (*name*, *value*) pair can be a tuple with two to four items, (*fn*, *fp*[, *ft*[, *fh*]]) (using square brackets as metasyntax to indicate optional parts). In this case, *fn* is the file's name, *fp* provides the contents (in just the same way as in the previous paragraph), optional *ft* provides the content type (if missing, `requests` guesses it, as in the previous paragraph), and the optional `dict` *fh* provides extra headers for the file's form part.

How to interpret requests examples

In practical applications, you don't usually need to consider the internal instance *r* of the class `requests.Request`, which functions like `requests.post` is building, preparing, and then sending on your behalf. However, to understand exactly what `requests` is doing, working at a lower level of abstraction (building, preparing, and examining *r*—no need to send it!) is instructive. For example, after importing `requests`, passing `data` as in the following example:

```
r = requests.Request('GET', 'http://www.example.com',
    data={'foo': 'bar'}, params={'fie': 'foo'})
p = r.prepare()
print(p.url)
print(p.headers)
print(p.body)
```

prints out (splitting the *p*.`headers` `dict`'s printout for readability):

```
http://www.example.com/?fie=foo
{'Content-Length': '7',
 'Content-Type': 'application/x-www-form-urlencoded'}
foo=bar
```

5 As it gives you complete, explicit control of exactly what octets are uploaded.

Similarly, when passing `files`:

```
r = requests.Request('POST', 'http://www.example.com',
    data={'foo': 'bar'}, files={'fie': 'foo'})
p = r.prepare()
print(p.headers)
print(p.body)
```

this prints out (with several lines split for readability):

```
{'Content-Length': '228',
 'Content-Type': 'multipart/form-data; boundary=dfd600d8aa58496270'}
b'--dfd600d8aa58496270\r\nContent-Disposition: form-data;
="foo"\r\n\r\nbar\r\n--dfd600d8aa584962709b936134b1cfce\r\n
Content-Disposition: form-data; name="fie" filename="fie"\r\n\r\nfoo\r\n
--dfd600d8aa584962709b936134b1cfce--\r\n'
```

Happy interactive exploring!

The Response class

The one class from the `requests` module that you always have to consider is `Response`: every request, once sent to the server (typically, that's done implicitly by methods such as `get`), returns an instance *r* of `requests.Response`.

The first thing you usually want to do is to check *r*`.status_code`, an `int` that tells you how the request went, in typical "HTTPese": `200` means "everything's fine," `404` means "not found," and so on. If you'd rather just get an exception for status codes indicating some kind of error, call *r*`.raise_for_status`; that does nothing if the request went fine, but raises `requests.exceptions.HTTPError` otherwise. (Other exceptions, not corresponding to any specific HTTP status code, can and do get raised without requiring any such explicit call: e.g., `ConnectionError` for any kind of network problem, or `TimeoutError` for a timeout.)

Next, you may want to check the response's HTTP headers: for that, use *r*`.headers`, a `dict` (with the special feature of having case-insensitive string-only keys indicating the header names as listed, e.g., in Wikipedia, per the HTTP specs). Most headers can be safely ignored, but sometimes you'd rather check. For example, you can verify whether the response specifies which natural language its body is written in, via *r*`.headers.get('content-language')`, to offer different presentation choices, such as the option to use some kind of language translation service to make the response more usable for the user.

You don't usually need to make specific status or header checks for redirects: by default, `requests` automatically follows redirects for all methods except HEAD (you can explicitly pass the `allow_redirection` named parameter in the request to alter that behavior). If you allow redirects, you may want to check *r*`.history`, a list of all `Response` instances accumulated along the way, oldest to newest, up to but excluding *r* itself (*r*`.history` is empty if there have been no redirects).

Most often, maybe after checking status and headers, you want to use the response's body. In simple cases, just access the response's body as a bytestring, `r.content`, or decode it as JSON (once you've checked that's how it's encoded, e.g., via `r.headers.get('content-type')`) by calling `r.json`.

Often, you'd rather access the response's body as (Unicode) text, with the property `r.text`. The latter gets decoded (from the octets that actually make up the response's body) with the codec `requests` thinks is best, based on the Content-Type header and a cursory examination of the body itself. You can check what codec has been used (or is about to be used) via the attribute `r.encoding`; its value will be the name of a codec registered with the `codecs` module, covered in "The codecs Module" on page 302. You can even *override* the choice of codec to use by *assigning* to `r.encoding` the name of the codec you choose.

We do not cover other advanced issues, such as streaming, in this book; see the `requests` package's online docs for further information.

Other Network Protocols

Many, *many* other network protocols are in use—a few are best supported by Python's standard library, but for most of them you'll find better and more recent third-party modules on PyPI.

To connect as if you were logging in to another machine (or a separate login session on your own node), you can use the Secure Shell (SSH) protocol, supported by the third-party module `paramiko` or the higher abstraction layer wrapper around it, the third-party module `spur`. (You can also, with some likely security risks, still use classic Telnet, supported by the standard library module `telnetlib`.)

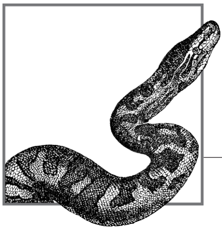
Other network protocols include, among many others:

- NNTP, to access Usenet News servers, supported by the standard library module `nntplib`
- XML-RPC, for a rudimentary remote procedure call functionality, supported by `xmlrpc.client`
- gRPC, for a more modern remote procedure functionality, supported by third-party module `grpcio`
- NTP, to get precise time off the network, supported by third-party module `ntplib`
- SNMP, for network management, supported by third-party module `pysnmp`

No single book (not even this one!) could possibly cover all these protocols and their supporting modules. Rather, our best suggestion in the matter is a strategic one: whenever you decide that your application needs to interact with some other system via a certain networking protocol, don't rush to implement your own modules to support that protocol. Instead, search and ask around, and you're likely to find excellent existing Python modules (third-party or standard-library ones) supporting that protocol.[6]

Should you find some bug or missing feature in such modules, open a bug or feature request (and, ideally, supply a patch or pull request that would fix the problem and satisfy your application's needs). In other words, become an active member of the open source community, rather than just a passive user: you will be welcome there, scratch your own itch, and help many others in the process. "Give forward," since you cannot "give back" to all the awesome people who contributed to give you most of the tools you're using!

6 Even more importantly, if you think you need to invent a brand-new protocol and implement it on top of sockets, think again, and search carefully: it's far more likely that one or more of the huge number of existing internet protocols meets your needs just fine!



20 Serving HTTP

When a browser (or any other web client) requests a page from a server, the server may return either static or dynamic content. Serving dynamic content involves server-side web programs generating and delivering content on the fly, often based on information stored in a database.

In the early history of the web, the standard for server-side programming was the *Common Gateway Interface* (CGI), which required the server to run a separate program each time a client requested dynamic content. Process startup time, interpreter initialization, connection to databases, and script initialization add up to measurable overhead; CGI did not scale well.

Nowadays, web servers support many server-specific ways to reduce overhead, serving dynamic content from processes that can serve for several hits rather than starting up a new process per hit. Therefore, we do not cover CGI in this book. To maintain existing CGI programs, or better yet, port them to more modern approaches, consult the online docs (especially PEP 594 for recommendations) and check out the standard library modules `cgi` (deprecated as of 3.11) and `http.cookies`.[1]

HTTP has become even more fundamental to distributed systems design with the emergence of systems based on microservices, offering a convenient way to transport between processes the JSON content that is frequently used. There are thousands of publicly available HTTP data APIs on the internet. While HTTP's

1 One historical legacy is that, in CGI, a server provided the CGI script with information about the HTTP request to be served mostly via the operating system's environment (in Python, that's `os.environ`); to this day, interfaces between web servers and application frameworks rely on "an environment" that's essentially a dictionary and generalizes and speeds up the same fundamental idea.

principles remain almost unchanged since its inception in the mid-1990s, it has been significantly enhanced over the years to extend its capabilities.[2] For a thorough grounding with excellent reference materials we recommend *HTTP: The Definitive Guide* by David Gourley et al. (O'Reilly).

http.server

Python's standard library includes a module containing the server and handler classes to implement a simple HTTP server.

You can run this server from the command line by just entering:

```
$ python -m http.server port_number
```

By default, the server listens on all interfaces and provides access to the files in the current directory. One author uses this as a simple means for file transfer: start up a Python `http.server` in the file directory on the source system, and then copy files to the destination using a utility such as `wget` or `curl`.

`http.server` has very limited security features. You can find further information on `http.server` in the online docs. For production use, we recommend that you use one of the frameworks mentioned in the following sections.

WSGI

Python's *Web Server Gateway Interface* (WSGI) is the standard way for all modern Python web development frameworks to interface with underlying web servers or gateways. WSGI is not meant for direct use by your application programs; rather, you code your programs using any one of many higher-abstraction frameworks, and the framework, in turn, uses WSGI to talk to the web server.

You need to care about the details of WSGI only if you're implementing the WSGI interface for a web server that doesn't already provide it (should any such server exist), or if you're building a new Python web framework.[3] In that case, study the WSGI PEP, the docs for the standard library package `wsgiref`, and the archive of WSGI.org.

A few WSGI concepts may be important to you if you use lightweight frameworks (i.e., ones that match WSGI closely). WSGI is an *interface*, and that interface has two sides: the *web server/gateway* side, and the *application/framework* side.

The framework side's job is to provide a *WSGI application* object, a callable object (often the instance of a class with a `__call__` special method, but that's an imple-

2 More advanced versions of HTTP exist, but we do not cover them in this book.

3 Please don't. As Titus Brown once pointed out, Python is (in)famous for having more web frameworks than keywords. One of this book's authors once showed Guido how to easily fix that problem when he was first designing Python 3—just add a few hundred new keywords—but, for some reason, Guido was not very receptive to this suggestion.

mentation detail) respecting conventions in the PEP, and to connect the application object to the server by whatever means the specific server documents (often a few lines of code, or configuration files, or just a convention such as naming the WSGI application object `application` as a top-level attribute in a module). The server calls the application object for each incoming HTTP request, and the application object responds appropriately so that the server can form the outgoing HTTP response and send it on—all according to said conventions. A framework, even a lightweight one, shields you from such details (except that you may have to instantiate and connect the application object, depending on the specific server).

WSGI Servers

An extensive list of servers and adapters you can use to run WSGI frameworks and applications (for development and testing, in production web setups, or both) is available online—extensive, but just partial. For example, it does not mention that Google App Engine's Python runtime is also a WSGI server, ready to dispatch WSGI apps as directed by the *app.yaml* configuration file.

If you're looking for a WSGI server to use for development, or to deploy in production behind, say, an Nginx-based load balancer, you should be happy, at least on Unix-like systems, with Gunicorn: pure Python goodness, supporting nothing but WSGI, very lightweight. A worthy (also pure Python and WSGI-only) alternative, currently with better Windows support, is Waitress. If you need richer features (such as support for Perl and Ruby as well as Python, and many other forms of extensibility), consider the bigger, more complex uWSGI.[4]

WSGI also has the concept of *middleware*, a subsystem that implements both the server and application sides of WSGI. A middleware object "wraps" a WSGI application; can selectively alter requests, environments, and responses; and presents itself to the server as "the application." Multiple layers of wrappers are allowed and common, forming a "stack" of middleware offering services to the actual application-level code. If you want to write a cross-framework middleware component, then you may, indeed, need to become a WSGI expert.

4 Installing uWSGI on Windows currently requires compiling it with Cygwin.

ASGI

If you're into asynchronous Python (which we don't cover in this book), you should definitely investigate ASGI, which sets out to do pretty much what WSGI does, but asynchronously. As is usually the case for asynchronous programs in a networking environment, it can offer greatly improved performance, albeit (arguably) with some increase in cognitive load for the developer.

Python Web Frameworks

For a survey of Python web frameworks, see the Python wiki page. It's authoritative since it's on the official Python.org website, and it's community curated, so it stays up-to-date as time goes by. The wiki lists and points to dozens of frameworks[5] that it identifies as "active," plus many more it identifies as "discontinued/inactive." In addition, it points to separate wiki pages about Python content management systems, web servers, and web components and libraries thereof.

"Full-Stack" Versus "Lightweight" Frameworks

Roughly speaking, Python web frameworks can be classified as being either *full-stack* (trying to supply all the functionality you may need to build a web application) or *lightweight* (supplying just a handy interface to web serving itself, and letting you pick and choose your own favorite components for tasks such as interfacing to databases and templating). Of course, like all taxonomies, this one is imprecise and incomplete, and requires value judgments; however, it's one way to start making sense of the many Python web frameworks.

In this book, we do not thoroughly cover any full-stack frameworks—each is far too complex. Nevertheless, one of them might be the best approach for your specific applications, so we do mention a few of the most popular ones, and recommend that you check out their websites.

A Few Popular Full-Stack Frameworks

By far the most popular full-stack framework is Django, which is sprawling and extensible. Django's so-called *applications* are in fact reusable subsystems, while what's normally called "an application" Django calls a *project*. Django requires its own unique mindset, but offers enormous power and functionality in return.

5 Since Python has fewer than 40 keywords, you can see why Titus Brown once pointed out that Python has more web frameworks than keywords.

An excellent alternative is web2py: it's just about as powerful, easier to learn, and well known for its dedication to backward compatibility (if it keeps up its great track record, any web2py application you code today will keep working far into the future). web2py also has outstanding documentation.

A third worthy contender is TurboGears, which starts out as a lightweight framework but achieves "full-stack" status by fully integrating other, independent third-party projects for the various other functionalities needed in most web apps, such as database interfacing and templating, rather than designing its own. Another somewhat philosophically similar "light but rich" framework is Pyramid.

Considerations When Using Lightweight Frameworks

Whenever you use a lightweight framework, if you need any database, templating, or other functionality not strictly related to HTTP, you'll be picking and choosing separate components for that purpose. However, the lighter in weight your framework, the more components you will need to understand and integrate, for purposes such as authenticating a user or maintaining state across web requests by a given user. Many WSGI middleware packages can help you with such tasks. Some excellent ones are quite focused—for example, Oso for access control, Beaker for maintaining state in the form of lightweight sessions of any one of several kinds, and so forth.

However, when we (the authors of this book) require good WSGI middleware for just about any purpose, we almost invariably first check Werkzeug, a collection of such components that's amazing in breadth and quality. We don't cover Werkzeug in this book (just as we don't cover other middleware), but we recommend it highly (Werkzeug is also the foundation on which Flask—our favorite lightweight framework, which we do cover later in this chapter—is built).

You may notice that properly using lightweight frameworks requires you to understand HTTP (in other words, to know what you're doing), while a full-stack framework tries to lead you by the hand and have you do the right thing without really needing to understand how or why it is right—at the cost of time and resources, and of accepting the full-stack framework's conceptual map and mindset. The authors of this book are enthusiasts of the knowledge-heavy, resources-light approach of lightweight frameworks, but we acknowledge that there are many situations where the rich, heavy, all-embracing full-stack frameworks are more appropriate. To each their own!

A Few Popular Lightweight Frameworks

As mentioned, Python has multiple frameworks, including many lightweight ones. We cover two of the latter here: the popular, general-purpose Flask, and API-centric FastAPI.

Flask

The most popular Python lightweight framework is Flask, a third-party `pip`-installable package. Although lightweight, it includes a development server and debugger, and it explicitly relies on other well-chosen packages such as Werkzeug for middleware and Jinja for templating (both packages were originally authored by Armin Ronacher, the author of Flask).

In addition to the project website (which includes rich, detailed docs), look at the sources on GitHub and the PyPI entry. If you want to run Flask on Google App Engine (locally on your computer, or on Google's servers at *appspot.com*), Dough Mahugh's Medium article can be quite handy.

We also highly recommend Miguel Grinberg's book *Flask Web Development* (O'Reilly): although the second edition is rather dated (almost four years old at the time of this writing), it still provides an excellent foundation, on top of which you'll have a far easier time learning the latest new additions.

The main class supplied by the `flask` package is named `Flask`. An instance of `flask.Flask`, besides being a WSGI application itself, also wraps a WSGI application as its `wsgi_app` property. When you need to further wrap the WSGI app in some WSGI middleware, use the idiom:

```
import flask

app = flask.Flask(__name__)
app.wsgi_app = some_middleware(app.wsgi_app)
```

When you instantiate `flask.Flask`, always pass it as the first argument the application name (often just the `__name__` special variable of the module where you instantiate it; if you instantiate it from within a package, usually in *__init__.py*, `__name__.partition('.')[0]` works). Optionally, you can also pass named parameters such as `static_folder` and `template_folder` to customize where static files and Jinja templates are found; however, that's rarely needed—the default values (subfolders named *static* and *templates*, respectively, located in the same folder as the Python script that instantiates `flask.Flask`) make perfect sense.

An instance *`app`* of `flask.Flask` supplies more than 100 methods and properties, many of them decorators to bind functions to *`app`* in various roles, such as *view functions* (serving HTTP verbs on a URL) or *hooks* (letting you alter a request before it's processed or a response after it's built, handling errors, and so forth).

`flask.Flask` takes just a few parameters at instantiation (and the ones it takes are not ones that you usually need to compute in your code), and it supplies decorators you'll want to use as you define, for example, view functions. Thus, the normal pattern in `flask` is to instantiate *`app`* early in your main script, just as your application is starting up, so that the app's decorators, and other methods and properties, are available as you **`def`** view functions and so on.

Since there is a single global *app* object, you may wonder how thread-safe it can be to access, mutate, and rebind *app*'s properties and attributes. Not to worry: the names you see are actually just proxies to actual objects living in the *context* of a specific request, in a specific thread or greenlet. Never type-check those properties (their types are in fact obscure proxy types), and you'll be fine.

Flask also supplies many other utility functions and classes; often, the latter subclass or wrap classes from other packages to add seamless, convenient Flask integration. For example, Flask's `Request` and `Response` classes add just a little handy functionality by subclassing the corresponding Werkzeug classes.

Flask request objects The class `flask.Request` supplies a large number of thoroughly documented properties. Table 20-1 lists the ones you'll be using most often.

Table 20-1. Useful properties of `flask.Request`

`args`	A `MultiDict` of the request's query arguments
`cookies`	A `dict` with the cookies from the request
`data`	A `bytes` string, the request's body (typically for POST and PUT requests)
`files`	A `MultiDict` of uploaded files in the request, mapping the files' names to file-like objects containing each file's data
`form`	A `MultiDict` with the request's form fields, provided in the request's body
`headers`	A `MultiDict` with the request's headers
`values`	A `MultiDict` combining the `args` and `form` properties

A `MultiDict` is like a `dict`, except that it can have multiple values for a key. Indexing and `get` on a `MultiDict` instance *m* return an arbitrary one of the values; to get the list of values for a key (an empty list, if the key is not in *m*), call `m.getlist(key)`.

Flask response objects Often, a Flask view function can just return a string (which becomes the response's body): Flask transparently wraps an instance *r* of `flask.Response` around the string, so you don't have to worry about the response class. However, sometimes you want to alter the response's headers; in this case, in the view function, call `r = flask.make_response(astring)`, alter `r.headers` as you want, then `return r`. (To set a cookie, don't use `r.headers`; rather, call `r.set_cookie`.)

Some of Flask's built-in integrations with other systems don't require subclassing: for example, the templating integration implicitly injects into the Jinja context the Flask globals `config`, `request`, `session`, and `g` (the latter being the handy "globals catch-all" object `flask.g`, a proxy in application context, in which your code can store whatever you want to "stash" for the duration of the request being served) and the functions `url_for` (to translate an endpoint to the corresponding URL, same as `flask.url_for`) and `get_flashed_messages` (to support *flashed messages*, which we do not cover in this book; same as `flask.get_flashed_messages`). Flask also provides convenient ways for your code to inject more filters, functions, and values into the Jinja context, without any subclassing.

Most of the officially recognized or approved Flask extensions (hundreds are available from PyPI at the time of this writing) adopt similar approaches, supplying classes and utility functions to seamlessly integrate other popular subsystems with your Flask applications.

In addition, Flask introduces other features, such as *signals* to provide looser dynamic coupling in a "pub/sub" pattern and *blueprints*, offering a substantial subset of a Flask application's functionality to ease refactoring large applications in highly modular, flexible ways. We do not cover these advanced concepts in this book.

Example 20-1 shows a simple Flask example. (After using `pip` to install Flask, run the example using the command **`flask --app flask_example run`**.)

Example 20-1. A Flask example

```
import datetime, flask
app = flask.Flask(__name__)

# secret key for cryptographic components such as encoding session cookies;
# for production use, use secrets.token_bytes()
app.secret_key = b'\xc5\x8f\xbc\xa2\x1d\xeb\xb3\x94;:d\x03'

@app.route('/')
def greet():
    lastvisit = flask.session.get('lastvisit')
    now = datetime.datetime.now()
    newvisit = now.ctime()
    template = '''
      <html><head><title>Hello, visitor!</title>
      </head><body>
      {% if lastvisit %}
        <p>Welcome back to this site!</p>
        <p>You last visited on {{lastvisit}} UTC</p>
        <p>This visit on {{newvisit}} UTC</p>
      {% else %}
        <p>Welcome to this site on your first visit!</p>
        <p>This visit on {{newvisit}} UTC</p>
        <p>Please Refresh the web page to proceed</p>
      {% endif %}
      </body></html>'''
    flask.session['lastvisit'] = newvisit
    return flask.render_template_string(
      template, newvisit=newvisit, lastvisit=lastvisit)
```

This example shows how to use just a few of the many building blocks that Flask offers—the `Flask` class, a view function, and rendering the response (in this case, using `render_template_string` on a Jinja template; in real life, templates are usually kept in separate files rendered with `render_template`). The example also shows how to maintain continuity of state among multiple interactions with the server from the same browser, with the handy `flask.session` variable. (It could alternatively have put together the HTML response in Python code instead of using Jinja, and used a cookie directly instead of the session; however, real-world Flask apps do tend to use Jinja and sessions by preference.)

If this app had multiple view functions, it might want to set `lastvisit` in the session to whatever URL had triggered the request. Here's how to code and decorate a hook function to execute after each request:

```
@app.after_request
def set_lastvisit(response):
    now = datetime.datetime.now()
    flask.session['lastvisit'] = now.ctime()
    return response
```

You can now remove the `flask.session['lastvisit'] = newvisit` statement from the view function `greet`, and the app will keep working fine.

FastAPI

FastAPI is of a more recent design than Flask or Django. While both of the latter have very usable extensions to provide API services, FastAPI aims squarely at producing HTTP-based APIs, as its name suggests. It's also perfectly capable of producing dynamic web pages intended for browser consumption, making it a versatile server. FastAPI's home page provides simple, short examples showing how it works and highlighting the advantages, backed up by very thorough and detailed reference documentation.

As type annotations (covered in Chapter 5) entered the Python language, they found wider use than originally intended in tools like `pydantic`, which uses them to perform runtime parsing and validation. The FastAPI server exploits this support for clean data structures, demonstrating great potential to improve web coding productivity through built-in and tailored conversion and validation of inputs.

FastAPI also relies on Starlette, a high-performance asynchronous web framework, which in turn uses an ASGI server such as Uvicorn or Hypercorn. You don't need to use async techniques directly to take advantage of FastAPI. You can write your application in more traditional Python style, though it might perform even faster if you do switch to the async style.

FastAPI's ability to provide type-accurate APIs (and automatically generated documentation for them) aligned with the types indicated by your annotations means it can provide automatic parsing of incoming data and conversion on both input and output.

Consider the sample code shown in Example 20-2, which defines a simple model for both `pydantic` and `mongoengine`. Each has four fields: `name` and `description` are strings, `price` and `tax` are decimal. Values are required for the `name` and `price` fields, but `description` and `tax` are optional. `pydantic` establishes a default value of **`None`** for the latter two fields; `mongoengine` does not store a value for fields whose value is **`None`**.

Example 20-2. models.py: `pydantic` and `mongoengine` data models

```
from decimal import Decimal
from pydantic import BaseModel, Field
from mongoengine import Document, StringField, DecimalField
from typing import Optional

class PItem(BaseModel):
    "pydantic typed data class."
    name: str
    price: Decimal
    description: Optional[str] = None
    tax: Optional[Decimal] = None

class MItem(Document):
    "mongoengine document."
    name = StringField(primary_key=True)
    price = DecimalField()
    description = StringField(required=False)
    tax = DecimalField(required=False)
```

Suppose you wanted to accept such data through a web form or as JSON, and be able to retrieve the data as JSON or display it in HTML. The skeletal Example 20-3 (offering no facilities to maintain existing data) shows you how you might do this with FastAPI. This example uses the Uvicorn HTTP server, but makes no attempt to explicitly use Python's async features. As with Flask, the program begins by creating an application object `app`. This object has decorator methods for each HTTP method, but the `app.route` decorator (while available) is eschewed in favor of `app.get` for HTTP GET, `app.post` for HTTP POST, and the like, and those determine which view function handles requests to the paths for different HTTP methods.

Example 20-3. server.py: FastAPI sample code to accept and display item data

```
from decimal import Decimal
from fastapi import FastAPI, Form
from fastapi.responses import HTMLResponse, FileResponse
from mongoengine import connect
from mongoengine.errors import NotUniqueError
from typing import Optional
import json
import uvicorn
from models import PItem, MItem

DATABASE_URI = "mongodb://localhost:27017"
db=DATABASE_URI+"/mydatabase"
connect(host=db)
app = FastAPI()

def save(item):
    try:
        return item.save(force_insert=True)
    except NotUniqueError:
        return None

@app.get('/')
def home_page():
    "View function to display a simple form."
    return FileResponse("index.html")

@app.post("/items/new/form/", response_class=HTMLResponse)
def create_item_from_form(name: str=Form(...),
                          price: Decimal=Form(...),
                          description: Optional[str]=Form(""),
                          tax: Optional[Decimal]=Form(Decimal("0.0"))):
    "View function to accept form data and create an item."
    mongoitem = MItem(name=name, price=price, description=description,
                      tax=tax)
    value = save(mongoitem)
    if value:
        body = f"Item({name!r}, {price!r}, {description!r}, {tax!r})"
    else:
        body = f"Item {name!r} already present."
    return f"""<html><body><h2>{body}</h2></body></html>"""

@app.post("/items/new/")
def create_item_from_json(item: PItem):
    "View function to accept JSON data and create an item."
    mongoitem = MItem(**item.dict())
    value = save(mongoitem)
    if not value:
        return f"Primary key {item.name!r} already present"
    return item.dict()
```

```python
@app.get("/items/{name}/")
def retrieve_item(name: str):
    "View function to return the JSON contents of an item."
    m_item = MItem.objects(name=name).get()
    return json.loads(m_item.to_json())

if __name__ == "__main__":
    # host as "localhost" or "127.0.0.1" allows only local apps to access the
    # web page. Using "0.0.0.0" will accept access from apps on other hosts,
    # but this can raise security concerns, and is generally not recommended.
    uvicorn.run("__main__:app", host="127.0.0.1", port=8000, reload=True)
```

The `home_page` function, which takes no arguments, simply renders a minimal HTML home page containing a form from the *index.html* file, shown in Example 20-4. The form posts to the */items/new/form/* endpoint, which triggers a call to the `create_item_from_form` function, which is declared in the routing decorator as producing an HTML response rather than the default JSON.

Example 20-4. The index.html file

```html
<!DOCTYPE html>
<html lang="en">
  <body>
  <h2>FastAPI Demonstrator</h2>
  <form method="POST" action="/items/new/form/">
    <table>
    <tr><td>Name</td><td><input name="name"></td></tr>
    <tr><td>Price</td><td><input name="price"></td></tr>
    <tr><td>Description</td><td><input name="description"></td></tr>
    <tr><td>Tax</td><td><input name="tax"></td></tr>
    <tr><td></td><td><input type="submit"></td></tr>
    </table>
  </form>
  </body>
</html>
```

The form, shown in Figure 20-1, is handled by the `create_item_from_form` function, whose signature takes an argument for each form field, with annotations defining each as a form field. Note that the signature defines its own default values for `description` and `tax`. The function creates an `MItem` object from the form data and tries to save it in the database. The `save` function forces insertions, inhibiting the update of an existing record, and reports failure by returning **`None`**; the return value is used to formulate a simple HTML reply. In a production application, a templating engine such as Jinja would typically be used to render the response.

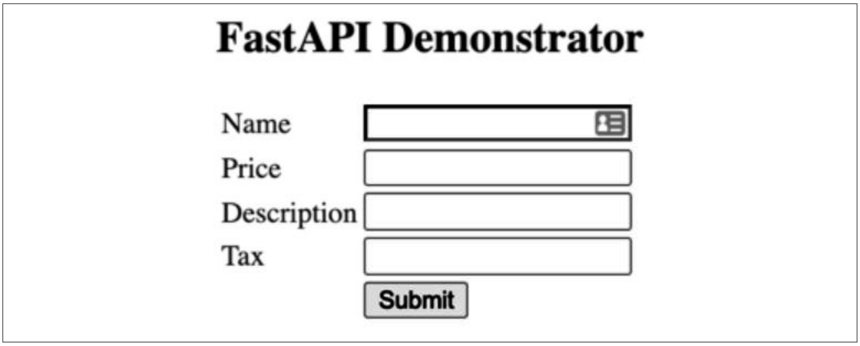


Figure 20-1. Input form for FastAPI Demonstrator

The `create_item_from_json` function, routed from the */items/new/* endpoint, takes JSON input from a POST request. Its signature accepts a `pydantic` record, so in this case, FastAPI will use `pydantic`'s validation to determine whether the input is acceptable. The function returns a Python dictionary, which FastAPI automatically converts to a JSON response. This can easily be tested with a simple client, shown in Example 20-5.

Example 20-5. FastAPI test client

```
import requests, json

result = requests.post('http://localhost:8000/items/new/',
                       json={"name": "Item1",
                             "price": 12.34,
                             "description": "Rusty old bucket"})
print(result.status_code, result.json())
result = requests.get('http://localhost:8000/items/Item1/')
print(result.status_code, result.json())
result = requests.post('http://localhost:8000/items/new/',
                       json={"name": "Item2",
                             "price": "Not a number"})
print(result.status_code, result.json())
```

The results of running this program are as follows:

```
200 {'name': 'Item1', 'price': 12.34, 'description': 'Rusty old
bucket'> 'tax': None}
200 {'_id': 'Item1', 'price': 12.34, 'description': 'Rusty old bucket'}
422 {'detail': [{'loc': ['body', 'price'], 'msg': 'value is not a valid
decimal', 'type': 'type_error.decimal'}]}
```

The first POST request to */items/new/* sees the server returning the same data it was presented with, confirming that it has been saved in the database. Note that the `tax` field was not supplied, so the `pydantic` default value is used here. The second line shows the output from retrieving the newly stored item (`mongoengine` identifies the primary key using the name `_id`). The third line shows an error message, generated by the attempt to store a nonnumeric value in the `price` field.

Finally, the `retrieve_item` view function, routed from URLs such as */items/Item1/*, extracts the key as the second path element and returns the JSON representation of the given item. It looks up the given key in `mongoengine` and converts the returned record to a dictionary that is rendered as JSON by FastAPI.

21

Email, MIME, and Other Network Encodings

What travels on a network are streams of bytes, also known in networking jargon as *octets*. Bytes can, of course, represent text, via any of several possible encodings. However, what you want to send over the network often has more structure than just a stream of text or bytes. The Multipurpose Internet Mail Extensions (MIME) and other encoding standards bridge the gap, by specifying how to represent structured data as bytes or text. While often originally designed for email, such encodings are also used on the web and in many other networked systems. Python supports such encodings through various library modules, such as `base64`, `quopri`, and `uu` (covered in "Encoding Binary Data as ASCII Text" on page 619), and the modules of the `email` package (covered in the following section). These encodings allow us, for example, to seamlessly create messages in one encoding containing attachments in another, avoiding many awkward tasks along the way.

MIME and Email Format Handling

The `email` package handles parsing, generation, and manipulation of MIME files such as email messages, Network News Transfer Protocol (NNTP) posts, HTTP interactions, and so on. The Python standard library also contains other modules that handle some parts of these jobs. However, the `email` package offers a complete and systematic approach to these important tasks. We suggest you use `email`, not the older modules that partially overlap with parts of `email`'s functionality. `email`, despite its name, need have nothing to do with receiving or sending email; for such tasks, see the modules `imaplib`, `poplib`, and `smtplib`, covered in "Email Protocols" on page 584. Rather, `email` deals with handling MIME messages (which may or may not be mail) after you receive them, or constructing them properly before you send them.

Functions in the email Package

The `email` package supplies four factory functions that return an instance *m* of the class `email.message.Message` from a string or file (see Table 21-1). These functions rely on the class `email.parser.Parser`, but the factory functions are handier and simpler. Therefore, we do not cover the `email.parser` module further in this book.

Table 21-1. `email` factory functions that build message objects from strings or files

`message_from_binary_file`	`message_from_binary_file(f)` Builds *m* by parsing the contents of binary file-like object *f*, which must be open for reading
`message_from_bytes`	`message_from_bytes(s)` Builds *m* by parsing bytestring *s*
`message_from_file`	`message_from_file(f)` Builds *m* by parsing the contents of text file-like object *f*, which must be open for reading
`message_from_string`	`message_from_string(s)` Builds *m* by parsing string *s*

The email.message Module

The `email.message` module supplies the class `Message`. All parts of the `email` package make, modify, or use instances of `Message`. An instance *m* of `Message` models a MIME message, including *headers* and a *payload* (data content). *m* is a mapping, with header names as keys, and header value strings as values.

To create an initially empty *m*, call `Message` with no arguments. More often, you create *m* by parsing via one of the factory functions in Table 21-1, or other indirect means such as the classes covered in "Creating Messages" on page 616. *m*'s payload can be a string, a single other instance of `Message`, or a *multipart message* (a recursively nested list of other `Message` instances).

You can set arbitrary headers on email messages you're building. Several internet RFCs specify headers for a wide variety of purposes. The main applicable RFC is RFC 2822; you can find a summary of many other RFCs about headers in nonnormative RFC 2076.

To make *m* more convenient, its semantics as a mapping are different from those of a `dict`. *m*'s keys are case insensitive. *m* keeps headers in the order in which you add them, and the methods `keys`, `values`, and `items` return lists (not views!) of headers in that order. *m* can have more than one header named *key*: *m*[*key*] returns an arbitrary such header (or **`None`** when the header is missing), and **`del`** *m*[*key*] deletes all of them (it's not an error if the header is missing).

To get a list of all headers with a certain name, call *m*`.get_all(`*key*`)`. `len(`*m*`)` returns the total number of headers, counting duplicates, not just the number of distinct header names. When there is no header named *key*, *m*[*key*] returns **None** and does not raise KeyError (i.e., it behaves like *m*.get(*key*)): **del** *m*[*key*] does nothing in this case, and *m*.get_all(*key*) returns **None**. You can loop directly on *m*: it's just like looping on *m*.keys() instead.

An instance *m* of Message supplies various attributes and methods that deal with *m*'s headers and payload, listed in Table 21-2.

Table 21-2. Attributes and methods of an instance m of Message

add_header	*m*.add_header(*_name*, *_value*, ***_params*) Like *m*[*_name*]=*_value*, but you can also supply header parameters as named arguments. For each named argument *pname*=*pvalue*, add_header changes any underscores in *pname* to dashes, then appends to the header's value a string of the form: ; *pname*="*pvalue*" When *pvalue* is **None**, add_header appends only a string of the form: ; *pname* When a parameter's value contains non-ASCII characters, specify it as a tuple with three items, (*CHARSET*, *LANGUAGE*, *VALUE*). *CHARSET* names the encoding to use for the value. *LANGUAGE* is usually **None** or '' but can be set any language value per RFC 2231; *VALUE* is the string value containing non-ASCII characters.
as_string	*m*.as_string(unixfrom=**False**) Returns the entire message as a string. When unixfrom is true, also includes a first line, normally starting with 'From ', known as the *envelope header* of the message.
attach	*m*.attach(*payload*) Adds *payload*, a message, to *m*'s payload. When *m*'s payload is **None**, *m*'s payload is now the single-item list [*payload*]. When *m*'s payload is a list of messages, appends *payload* to the list. When *m*'s payload is anything else, *m*.attach(*payload*) raises MultipartConversionError.
epilogue	The attribute *m*.epilogue can be **None**, or a string that becomes part of the message's string form after the last boundary line. Mail programs normally don't display this text. epilogue is a normal attribute of *m*: your program can access it when you're handling any *m*, and bind it when you're building or modifying *m*.
get_all	*m*.get_all(*name*, default=**None**) Returns a list with all values of headers named *name* in the order in which the headers are added to *m*. When *m* has no header named *name*, get_all returns default.
get_boundary	*m*.get_boundary(default=**None**) Returns the string value of the boundary parameter of *m*'s Content-Type header. When *m* has no Content-Type header, or the header has no boundary parameter, get_boundary returns default.
get_charsets	*m*.get_charsets(default=**None**) Returns the list *L* of string values of parameter charset of *m*'s Content-Type header. When *m* is multipart, *L* has one item per part; otherwise, *L* has length 1. For parts that have no Content-Type header, no charset parameter, or a main type different from 'text', the corresponding item in *L* is default.

get_content_maintype	*m*.get_content_maintype(default=**None**) Returns *m*'s main content type: a lowercase string '*maintype*' taken from header Content-Type. For example, when Content-Type is 'Text/Html', get_content_maintype returns 'text'. When *m* has no Content-Type header, get_content_maintype returns default.
get_content_subtype	*m*.get_content_subtype(default=**None**) Returns *m*'s content subtype: a lowercase string '*subtype*' taken from header Content-Type. For example, when Content-Type is 'Text/Html', get_content_subtype returns 'html'. When *m* has no Content-Type header, get_content_subtype returns default.
get_content_type	*m*.get_content_type(default=**None**) Returns *m*'s content type: a lowercase string '*maintype/subtype*' taken from header Content-Type. For example, when Content-Type is 'Text/Html', get_content_type returns 'text/html'. When *m* has no Content-Type header, get_content_type returns default.
get_filename	*m*.get_filename(default=**None**) Returns the string value of the filename parameter of *m*'s Content-Disposition header. When *m* has no Content-Disposition header, or the header has no filename parameter, get_filename returns default.
get_param	*m*.get_param(*param*, default=**None**, header='Content-Type') Returns the string value of parameter *param* of *m*'s header header. Returns '' for a parameter specified just by name (without a value). When *m* has no header header, or the header has no parameter named *param*, get_param returns default.
get_params	*m*.get_params(default=**None**, header='Content-Type') Returns the parameters of *m*'s header header, a list of pairs of strings that give each parameter's name and value. Uses '' as the value for parameters specified just by name (without a value). When *m* has no header header, get_params returns default.
get_payload	*m*.get_payload(i=**None**, decode=**False**) Returns *m*'s payload. When *m*.is_multipart is **False**, i must be **None**, and *m*.get_payload returns *m*'s entire payload, a string or Message instance. If decode is true and the value of header Content-Transfer-Encoding is either 'quoted-printable' or 'base64', *m*.get_payload also decodes the payload. If decode is false, or header Content-Transfer-Encoding is missing or has other values, *m*.get_payload returns the payload unchanged. When *m*.is_multipart is **True**, decode must be false. When i is **None**, *m*.get_payload returns *m*'s payload as a list. Otherwise, *m*.get_payload(*i*) returns the *i*th item of the payload, or raises TypeError if *i* < 0 or i is too large.
get_unixfrom	*m*.get_unixfrom() Returns the envelope header string for *m*, or **None** when *m* has no envelope header.
is_multipart	*m*.is_multipart() Returns **True** when *m*'s payload is a list; otherwise, returns **False**.

`preamble`	Attribute *m*.`preamble` can be **None**, or a string that becomes part of the message's string form before the first boundary line. A mail program shows this text only if it doesn't support multipart messages, so you can use this attribute to alert the user that your message is multipart and a different mail program is needed to view it. `preamble` is a normal attribute of *m*: your program can access it when you're handling an *m* that is built by whatever means, and bind, rebind, or unbind it when you're building or modifying *m*.
`set_boundary`	*m*.`set_boundary(`*boundary*`)` Sets the `boundary` parameter of *m*'s Content-Type header to *boundary*. When *m* has no Content-Type header, raises `HeaderParseError`.
`set_payload`	*m*.`set_payload(`*payload*`)` Sets *m*'s payload to *payload*, which must be a string, or a list of `Message` instances, as appropriate to *m*'s Content-Type.
`set_unixfrom`	*m*.`set_unixfrom(`*unixfrom*`)` Sets the envelope header string for *m*. *unixfrom* is the entire envelope header line, including the leading `'From '` but *not* including the trailing `'\n'`.
`walk`	*m*.`walk()` Returns an iterator on all parts and subparts of *m* to walk the tree of parts, depth-first (see "Recursion" on page 112).

The email.Generator Module

The `email.Generator` module supplies the class `Generator`, which you can use to generate the textual form of a message *m*. *m*.`as_string()` and `str(`*m*`)` may be enough, but `Generator` gives more flexibility. Instantiate the `Generator` class with a mandatory argument, *outfp*, and two optional arguments:

Generator **class** `Generator(`*outfp*`, mangle_from_=`**False**`, maxheaderlen=78)`

outfp is a file or file-like object that supplies the method `write`. When `man gle_from_` is true, *g* prepends a greater-than sign (>) to any line in the payload that starts with `'From '`, to make the message's textual form easier to parse. *g* wraps each header line, at semicolons, into physical lines of no more than `maxheaderlen` characters. To use *g*, call *g*.`flatten`; for example:

```
g.flatten(m, unixfrom=False)
```

This emits *m* as text to *outfp*, like (but consuming less memory than):

```
outfp.write(m.as_string(unixfrom))
```

.

Creating Messages

The subpackage `email.mime` supplies various modules, each with a subclass of `Message` named like the module. The modules' names are lowercase (e.g., `email.mime.text`), while the class names are in mixed case. These classes, listed in Table 21-3, help you create `Message` instances of different MIME types.

Table 21-3. Classes supplied by `email.mime`

`MIMEAudio`	**class** `MIMEAudio(_audiodata, _subtype=None, _encoder=None, **_params)` Creates MIME message objects of major type 'audio'. `_audiodata` is a bytestring of audio data to pack in a message of MIME type `'audio/_subtype'`. When `_subtype` is **None**, `_audiodata` must be parsable by standard Python library module `sndhdr` to determine the subtype; otherwise, `MIMEAudio` raises `TypeError`. **3.11+** Since `sndhdr` is deprecated, you should always specify the `_subtype`. When `_encoder` is **None**, `MIMEAudio` encodes data as Base64, which is usually optimal. Otherwise, `_encoder` must be callable with one parameter, *m*, which is the message being constructed; `_encoder` must then call `m.get_payload` to get the payload, encode the payload, put the encoded form back by calling `m.set_payload`, and set *m*'s Content-Transfer-Encoding header. `MIMEAudio` passes the `_params` dictionary of named argument names and values to `m.add_header` to construct *m*'s Content-Type header.

`MIMEBase`	**class** `MIMEBase(_maintype, _subtype, **_params)`
	Base class of all MIME classes; extends `Message`. Instantiating:
	`m = MIMEBase(mainsub, **params)`
	is equivalent to the longer and slightly less convenient idiom:
	`m = Message()`
	`m.add_header('Content-Type', f'{main}/{sub}',`
	`                  **params)`
	`m.add_header('Mime-Version', '1.0')`

`MIMEImage`	**class** `MIMEImage(_imagedata, _subtype=None, _encoder=None, **_params)` Like `MIMEAudio`, but with main type `'image'`; uses standard Python module `imghdr` to determine the subtype, if needed. **3.11+** Since `imghdr` is deprecated, you should always specify the `_subtype`.
`MIMEMessage`	**class** `MIMEMessage(msg, _subtype='rfc822')` Packs *msg*, which must be an instance of `Message` (or a subclass), as the payload of a message of MIME type `'message/_subtype'`.
`MIMEText`	**class** `MIMEText(_text, _subtype='plain', _charset='us-ascii', _encoder=None)` Packs text string `_text` as the payload of a message of MIME type `'text/_subtype'` with the given `_charset`. When `_encoder` is **None**, `MIMEText` does not encode the text, which is generally the best choice. Otherwise, `_encoder` must be callable with one parameter, *m*, which is the message being constructed; `_encoder` must then call `m.get_payload` to get the payload, encode the payload, put the encoded form back by calling `m.set_payload`, and set *m*'s Content-Transfer-Encoding header appropriately.

The email.encoders Module

The `email.encoders` module supplies functions that take a *nonmultipart* message *m* as their only argument, encode *m*'s payload, and set *m*'s headers appropriately. These functions are listed in Table 21-4.

Table 21-4. Functions of the `email.encoders` module

`encode_base64`	`encode_base64(m)` Uses Base64 encoding, usually optimal for arbitrary binary data (see "The base64 Module" on page 620).
`encode_noop`	`encode_noop(m)` Does nothing to *m*'s payload and headers.
`encode_quopri`	`encode_quopri(m)` Uses Quoted Printable encoding, usually optimal for text that is almost but not fully ASCII (see "The quopri Module" on page 621).
`encode_7or8bit`	`encode_7or8bit(m)` Does nothing to *m*'s payload, but sets the header Content-Transfer-Encoding to `'8bit'` when any byte of *m*'s payload has the high bit set; otherwise, sets it to `'7bit'`.

The email.utils Module

The `email.utils` module supplies several functions for email processing, listed in Table 21-5.

Table 21-5. Functions of the `email.utils` module

`formataddr`	`formataddr(pair)` Takes a pair of strings `(realname, email_address)` and returns a string *s* with the address to insert in header fields such as `To` and `Cc`. When *realname* is false (e.g., the empty string, `''`), `formataddr` returns *email_address*.
`formatdate`	`formatdate(timeval=None, localtime=False)` Returns a string with the time instant formatted as specified by RFC 2822. `timeval` is a number of seconds since the epoch. When `timeval` is **None**, `formatdate` uses the current time. When `localtime` is **True**, `formatdate` uses the local time zone; otherwise, it uses UTC.
`getaddresses`	`getaddresses(L)` Parses each item of *L*, a list of address strings as used in header fields such as `To` and `Cc`, and returns a list of pairs of strings `(name, address)`. When `getaddresses` cannot parse an item of *L* as an email address, it sets `('', '')` as the corresponding item in the list.

`mktime_tz`	`mktime_tz(`*`t`*`)` Returns a `float` representing the number of seconds since the epoch, in UTC, corresponding to the instant that *`t`* denotes. *`t`* is a tuple with 10 items. The first nine items of *`t`* are in the same format used in the module `time`, covered in "The time Module" on page 411. *`t`*`[-1]` is a time zone as an offset in seconds from UTC (with the opposite sign from `time.timezone`, as specified by RFC 2822). When *`t`*`[-1]` is **None**, `mktime_tz` uses the local time zone.
`parseaddr`	`parseaddr(`*`s`*`)` Parses string *`s`*, which contains an address as typically specified in header fields such as `To` and `Cc`, and returns a pair of strings `(`*`realname`*`,` *`address`*`)`. When `parseaddr` cannot parse *`s`* as an address, it returns `('', '')`.
`parsedate`	`parsedate(`*`s`*`)` Parses string *`s`* as per the rules in RFC 2822 and returns a tuple *`t`* with nine items, as used in the module `time`, covered in "The time Module" on page 411 (the items *`t`*`[-3:]` are not meaningful). `parsedate` also attempts to parse some erroneous variations on RFC 2822 that commonly encountered mailers use. When `parsedate` cannot parse *`s`*, it returns `None`.
`parsedate_tz`	`parsedate_tz(`*`s`*`)` Like `parsedate`, but returns a tuple *`t`* with 10 items, where *`t`*`[-1]` is *`s`*'s time zone as an offset in seconds from UTC (with the opposite sign from `time.timezone`, as specified by RFC 2822), like in the argument that `mktime_tz` accepts. Items *`t`*`[-4:-1]` are not meaningful. When *`s`* has no time zone, *`t`*`[-1]` is **None**.
`quote`	`quote(`*`s`*`)` Returns a copy of string *`s`*, where each double quote (") becomes `'\"'`, and each existing backslash is repeated.
`unquote`	`unquote(`*`s`*`)` Returns a copy of string *`s`* where leading and trailing double-quote characters (") and angle brackets (<>) are removed if they surround the rest of *`s`*.

Example Uses of the email Package

The `email` package helps you both in reading and composing email and email-like messages (but it's not involved in receiving and transmitting such messages: those tasks belong to separate modules covered in Chapter 19). Here is an example of how to use `email` to read a possibly multipart message and unpack each part into a file in a given directory:

```
import pathlib, email
def unpack_mail(mail_file, dest_dir):
    '''Given file object mail_file, open for reading, and dest_dir,
       a string that is a path to an existing, writable directory,
       unpack each part of the mail message from mail_file to a
       file within dest_dir.
    '''
    dest_dir_path = pathlib.Path(dest_dir)
    with mail_file:
        msg = email.message_from_file(mail_file)
```

```
    for part_number, part in enumerate(msg.walk()):
        if part.get_content_maintype() == 'multipart':
            # we get each specific part later in the loop,
            # so, nothing to do for the 'multipart' itself
            continue
        dest = part.get_filename()
        if dest is None: dest = part.get_param('name')
        if dest is None: dest = f'part-{part_number}'
        # in real life, make sure that dest is a reasonable filename
        # for your OS; otherwise, mangle that name until it is
        part_payload = part.get_payload(decode=True)
        (dest_dir_path / dest).write_text(part_payload)
```

And here is an example that performs roughly the reverse task, packaging all files that are directly under a given source directory into a single file suitable for mailing:

```
def pack_mail(source_dir, **headers):
    '''Given source_dir, a string that is a path to an existing,
       readable directory, and arbitrary header name/value pairs
       passed in as named arguments, packs all the files directly
       under source_dir (assumed to be plain text files) into a
       mail message returned as a MIME-formatted string.
    '''
    source_dir_path = pathlib.Path(source_dir)
    msg = email.message.Message()
    for name, value in headers.items():
        msg[name] = value
    msg['Content-type'] = 'multipart/mixed'
    filepaths = [path for path in source_dir_path.iterdir()
                 if path.is_file()]
    for filepath in filepaths:
        m = email.message.Message()
        m.add_header('Content-type', 'text/plain', name=filename)
        m.set_payload(filepath.read_text())
        msg.attach(m)
    return msg.as_string()
```

Encoding Binary Data as ASCII Text

Several kinds of media (e.g., email messages) can contain only ASCII text. When you want to transmit arbitrary binary data via such media, you need to encode the data as ASCII text strings. The Python standard library supplies modules that support the standard encodings known as Base64, Quoted Printable, and Unix-to-Unix, described in the following sections.

The base64 Module

The `base64` module supports the encodings specified in RFC 3548 as Base16, Base32, and Base64. Each of these encodings is a compact way to represent arbitrary binary data as ASCII text, without any attempt to produce human-readable results. `base64` supplies 10 functions: 6 for Base64, plus 2 each for Base32 and Base16. The six Base64 functions are listed in Table 21-6.

Table 21-6. Base64 functions of the `base64` module

`b64decode`	`b64decode(`*`s`*`, altchars=`**`None`**`, validate=`**`False`**`)` Decodes B64-encoded bytestring *`s`*, and returns the decoded bytestring. `altchars`, if not **`None`**, must be a bytestring of at least two characters (extra characters are ignored) specifying the two nonstandard characters to use instead of + and `/` (potentially useful to decode URL-safe or filesystem-safe B64-encoded strings). When `validate` is **`True`**, the call raises an exception if *`s`* contains any bytes that are not valid in B64-encoded strings (by default, such bytes are just ignored and skipped). Also raises an exception when *`s`* is improperly padded according to the Base64 standard.
`b64encode`	`b64encode(`*`s`*`, altchars=`**`None`**`)` Encodes bytestring *`s`* and returns the bytestring with the corresponding B64-encoded data. `altchars`, if not **`None`**, must be a bytestring of at least two characters (extra characters are ignored) specifying the two nonstandard characters to use instead of + and `/` (potentially useful to make URL-safe or filesystem-safe B64-encoded strings).
`standard_b64decode`	`standard_b64decode(`*`s`*`)` Like `b64decode(`*`s`*`)`.
`standard_b64encode`	`standard_b64encode(`*`s`*`)` Like `b64encode(`*`s`*`)`.
`urlsafe_b64decode`	`urlsafe_b64decode(`*`s`*`)` Like `b64decode(`*`s`*`, '-_')`.
`urlsafe_b64encode`	`urlsafe_b64encode(`*`s`*`)` Like `b64encode(`*`s`*`, '-_')`.

The four Base16 and Base32 functions are listed in Table 21-7.

Table 21-7. Base16 and Base32 functions of the `base64` module

`b16decode`	`b16decode(`*`s`*`, casefold=`**`False`**`)` Decodes B16-encoded bytestring *`s`*, and returns the decoded bytestring. When `casefold` is **`True`**, lowercase characters in *`s`* are treated like their uppercase equivalents; by default, when lowercase characters are present, the call raises an exception.
`b16encode`	`b16encode(`*`s`*`)` Encodes bytestring *`s`*, and returns the bytestring with the corresponding B16-encoded data.

b32decode	`b32decode(s, casefold=False, map01=None)` Decodes B32-encoded bytestring *s*, and returns the decoded bytestring. When `casefold` is `True`, lowercase characters in *s* are treated like their uppercase equivalents; by default, when lowercase characters are present, the call raises an exception. When `map01` is `None`, characters `0` and `1` are not allowed in the input; when not `None`, it must be a single-character bytestring specifying what `1` is mapped to (lowercase `'l'` or uppercase `'L'`); `0` is then always mapped to uppercase `'O'`.
b32encode	`b32encode(s)` Encodes bytestring *s* and returns the bytestring with the corresponding B32-encoded data.

The module also supplies functions to encode and decode the nonstandard but popular encodings Base85 and Ascii85, which, while not codified in RFCs or compatible with each other, can offer space savings of 15% by using larger alphabets for encoded bytestrings. See the online docs for details on those functions.

Email, MIME, and Encodings

The quopri Module

The `quopri` module supports the encoding specified in RFC 1521 as *Quoted Printable* (QP). QP can represent any binary data as ASCII text, but it's mainly intended for data that is mostly text, with a small amount of characters with the high bit set (i.e., characters outside the ASCII range). For such data, QP produces results that are both compact and human-readable. The `quopri` module supplies four functions, listed in Table 21-8.

Table 21-8. Functions of the `quopri` module

decode	`decode(infile, outfile, header=False)` Reads the binary file-like object *infile* by calling *infile*`.readline` until end-of-file (i.e., until a call to *infile*`.readline` returns an empty string), decodes the QP-encoded ASCII text thus read, and writes the results to binary file-like object *outfile*. When `header` is true, `decode` also turns _ (underscores) into spaces (per RFC 1522).
decode string	`decodestring(s, header=False)` Decodes bytestring *s*, QP-encoded ASCII text, and returns the bytestring with the decoded data. When `header` is true, `decodestring` also turns _ (underscores) into spaces.
encode	`encode(infile, outfile, quotetabs, header=False)` Reads binary file-like object *infile* by calling *infile*`.readline` until end-of-file (i.e., until a call to *infile*`.readline` returns an empty string), encodes the data thus read in QP, and writes the encoded ASCII text to binary file-like object *outfile*. When *quotetabs* is true, `encode` also encodes spaces and tabs. When `header` is true, `encode` encodes spaces as _ (underscores).
encode string	`encodestring(s, quotetabs=False, header=False)` Encodes bytestring *s*, which contains arbitrary bytes, and returns a bytestring with QP-encoded ASCII text. When `quotetabs` is true, `encodestring` also encodes spaces and tabs. When `header` is true, `encodestring` encodes spaces as _ (underscores).

The uu Module

The `uu` module[1] supports the classic *Unix-to-Unix* (UU) encoding, as implemented by the Unix programs *uuencode* and *uudecode*. UU starts encoded data with a `begin` line, which includes the filename and permissions of the file being encoded, and ends it with an `end` line. Therefore, UU encoding lets you embed encoded data in otherwise unstructured text, while Base64 encoding (discussed in "The base64 Module" on page 620) relies on the existence of other indications of where the encoded data starts and finishes. The `uu` module supplies two functions, listed in Table 21-9.

Table 21-9. Functions of the uu module

`decode`	`decode(`*`infile`*`, outfile=`**`None`**`, mode=`**`None`**`)` Reads the file-like object *`infile`* by calling *`infile`*`.readline` until end-of-file (i.e., until a call to *`infile`*`.readline` returns an empty string) or until a terminator line (the string `'end'` surrounded by any amount of whitespace). `decode` decodes the UU-encoded text thus read and writes the decoded data to the file-like object `outfile`. When `outfile` is **`None`**, `decode` creates the file specified in the UU-format `begin` line, with the permission bits given by `mode` (the permission bits specified in the `begin` line, when `mode` is **`None`**). In this case, `decode` raises an exception if the file already exists.
`encode`	`encode(`*`infile`*`,`*`outfile`*`, name='-', mode=0o666)` Reads the file-like object *`infile`* by calling *`infile`*`.read` (45 bytes at a time, which is the amount of data that UU encodes into 60 characters in each output line) until end-of-file (i.e., until a call to *`infile`*`.read` returns an empty string). It encodes the data thus read in UU and writes the encoded text to file-like object *`outfile`*. `encode` also writes a UU-format `begin` line before the text and a UU-format `end` line after the text. In the `begin` line, `encode` specifies the filename as `name` and the mode as `mode`.

1 Deprecated in Python 3.11, to be removed in Python 3.13; the online docs direct users to update existing code to use the `base64` module for data content and MIME headers for metadata.

22
Structured Text: HTML

Most documents on the web use HTML, the HyperText Markup Language. *Markup* is the insertion of special tokens, known as *tags*, in a text document, to structure the text. HTML is, in theory, an application of the large, general standard known as SGML, the Standard Generalized Markup Language. In practice, many documents on the web use HTML in sloppy or incorrect ways.

HTML was designed for presenting documents in a browser. As web content evolved, users realized it lacked the capability for *semantic markup*, in which the markup indicates the meaning of the delineated text rather than simply its appearance. Complete, precise extraction of the information in an HTML document often turns out to be unfeasible. A more rigorous standard called XHTML attempted to remedy these shortcomings. XHTML is similar to traditional HTML, but it is defined in terms of XML, the eXtensible Markup Language, and more precisely than HTML. You can handle well-formed XHTML with the tools covered in Chapter 23. However, as of this writing, XHTML has not enjoyed overwhelming success, getting scooped instead by the more pragmatic HTML5.

Despite the difficulties, it's often possible to extract at least some useful information from HTML documents (a task known as *web scraping*, *spidering*, or just *scraping*). Python's standard library tries to help, supplying the `html` package for the task of parsing HTML documents, whether for the purpose of presenting the documents or, more typically, as part of an attempt to extract information from them. However, when you're dealing with somewhat-broken web pages (which is almost always the case!), the third-party module `BeautifulSoup` usually offers your last, best hope. In this book, for pragmatic reasons, we mostly cover `BeautifulSoup`, ignoring the standard library modules competing with it. The reader looking for alternatives should also investigate the increasingly popular `scrapy` package.

Generating HTML and embedding Python in HTML are also reasonably frequent tasks. The standard Python library doesn't support HTML generation or embedding, but you can use Python string formatting, and third-party modules can also help. `BeautifulSoup` lets you alter an HTML tree (so, in particular, you can build one up programmatically, even "from scratch"); an often preferable alternative approach is *templating*, supported, for example, by the third-party module `jinja2`, whose bare essentials we cover in "The jinja2 Package" on page 639.

The html.entities Module

The `html.entities` module in Python's standard library supplies a few attributes, all of them mappings (see Table 22-1). They come in handy whatever general approach you're using to parse, edit, or generate HTML, including the `BeautifulSoup` package covered in the following section.

Table 22-1. Attributes of `html.entities`

`codepoint2name`	A mapping from Unicode codepoints to HTML entity names. For example, `entities.codepoint2name[228]` is `'auml'`, since Unicode character 228, ä, "lowercase a with diaeresis," is encoded in HTML as `'ä'`.
`entitydefs`	A mapping from HTML entity names to Unicode equivalent single-character strings. For example, `entities.entitydefs['auml']` is `'ä'`, and `entities.entitydefs['sigma']` is `'σ'`.
`html5`	A mapping from HTML5 named character references to equivalent single-character strings. For example, `entities.html5['gt;']` is `'>'`. The trailing semicolon in the key *does* matter—a few, but far from all, HTML5 named character references can optionally be spelled without a trailing semicolon, and in those cases both keys (with and without the trailing semicolon) are present in `entities.html5`.
`name2codepoint`	A mapping from HTML entity names to Unicode codepoints. For example, `entities.name2codepoint['auml']` is 228.

The BeautifulSoup Third-Party Package

`BeautifulSoup` lets you parse HTML even if it's rather badly formed. It uses simple heuristics to compensate for typical HTML brokenness, and succeeds at this hard task surprisingly well in most cases. The current major version of `BeautifulSoup` is version 4, also known as `bs4`. In this book, we specifically cover version 4.10; as of this writing, that's the latest stable version of `bs4`.

Installing Versus Importing BeautifulSoup

`BeautifulSoup` is one of those annoying modules whose packaging requires you to use different names inside and outside Python. You install the module by running **`pip install beautifulsoup4`** at a shell command prompt, but when you import it in your Python code, you use **`import`** `bs4`.

The BeautifulSoup Class

The bs4 module supplies the BeautifulSoup class, which you instantiate by calling it with one or two arguments: first, htmltext—either a file-like object (which is read to get the HTML text to parse) or a string (which is the text to parse)—and second, an optional parser argument.

Which parser BeautifulSoup uses

If you don't pass a parser argument, BeautifulSoup "sniffs around" to pick the best parser (but you may get a GuessedAtParserWarning warning in this case). If you haven't installed any other parser, BeautifulSoup defaults to html.parser from the Python standard library; if you have other parsers installed, BeautifulSoup defaults to one of them (lxml is currently the preferred one). Unless specified otherwise, the following examples use the default Python html.parser. To get more control and to avoid the differences between parsers mentioned in the BeautifulSoup documentation, pass the name of the parser library to use as the second argument as you instantiate BeautifulSoup.[1]

For example, if you have installed the third-party package html5lib (to parse HTML in the same way as all major browsers do, albeit slowly), you may call:

```
soup = bs4.BeautifulSoup(thedoc, 'html5lib')
```

When you pass 'xml' as the second argument, you must already have the third-party package lxml installed. BeautifulSoup then parses the document as XML, rather than as HTML. In this case, the attribute is_xml of soup is **True**; otherwise, soup.is_xml is **False**. You can also use lxml to parse HTML, if you pass 'lxml' as the second argument. More generally, you may need to install the appropriate parser library depending on the second argument you choose to pass to a call to bs4.BeautifulSoup; BeautifulSoup reminds you with a warning message if you don't.

Here's an example of using different parsers on the same string:

```
>>> import bs4, lxml, html5lib
>>> sh = bs4.BeautifulSoup('<p>hello', 'html.parser')
>>> sx = bs4.BeautifulSoup('<p>hello', 'xml')
>>> sl = bs4.BeautifulSoup('<p>hello', 'lxml')
>>> s5 = bs4.BeautifulSoup('<p>hello', 'html5lib')
>>> for s in [sh, sx, sl, s5]:
...   print(s, s.is_xml)
...

<p>hello</p> False
<?xml version="1.0" encoding="utf-8"?>
```

1 The BeautifulSoup documentation provides detailed information about installing various parsers.

```
<p>hello</p> True
<html><body><p>hello</p></body></html> False
<html><head></head><body><p>hello</p></body></html> False
```

Differences between parsers in fixing invalid HTML input

In the preceding example, `'html.parser'` simply inserts the end tag `</p>`, missing from the input. Other parsers vary in the degree to which they repair invalid HTML input by adding required tags, such as `<html>`, `<head>`, and `<body>`, as you can see in the example.

BeautifulSoup, Unicode, and encoding

`BeautifulSoup` uses Unicode, deducing or guessing the encoding[2] when the input is a bytestring or binary file. For output, the `prettify` method returns a `str` representation of the tree, including tags and their attributes. `prettify` formats the string with whitespace and newlines added to indent elements, displaying the nesting structure. To have it instead return a `bytes` object (a bytestring) in a given encoding, pass it the encoding name as an argument. If you don't want the result to be "prettified," use the `encode` method to get a bytestring, and the `decode` method to get a Unicode string. For example:

```
>>> s = bs4.BeautifulSoup('<p>hello', 'html.parser')
>>> print(s.prettify())

<p>
 hello
</p>

>>> print(s.decode())

<p>hello</p>

>>> print(s.encode())

b'<p>hello</p>'
```

The Navigable Classes of bs4

An instance *b* of class `BeautifulSoup` supplies attributes and methods to "navigate" the parsed HTML tree, returning instances of *navigable classes* `Tag` and `NavigableString`, along with subclasses of `NavigableString` (`CData`, `Comment`, `Declaration`, `Doctype`, and `ProcessingInstruction`, differing only in how they are emitted when you output them).

Each instance of a navigable class lets you keep navigating—i.e., dig for more information—with pretty much the same set of navigational attributes and search meth-

2 As explained in the `BeautifulSoup` documentation, which also shows various ways to guide, or completely override, `BeautifulSoup`'s guesses about encoding.

ods as *b* itself. There are differences: instances of Tag can have HTML attributes and child nodes in the HTML tree, while instances of NavigableString cannot (instances of NavigableString always have one text string, a parent Tag, and zero or more siblings, i.e., other children of the same parent tag).

Navigable Class Terminology

When we say "instances of NavigableString," we include instances of any of its subclasses; when we say "instances of Tag," we include instances of BeautifulSoup since the latter is a subclass of Tag. Instances of navigable classes are also known as the *elements* or *nodes* of the tree.

All instances of navigable classes have attribute name: it's the tag string for Tag instances, '[document]' for BeautifulSoup instances, and **None** for instances of NavigableString.

Instances of Tag let you access their HTML attributes by indexing, or you can get them all as a dict via the .attrs Python attribute of the instance.

Indexing instances of Tag

When *t* is an instance of Tag, *t*['foo'] looks for an HTML attribute named foo within *t*'s HTML attributes and returns the string for the foo attribute. When *t* has no HTML attribute named foo, *t*['foo'] raises a KeyError exception; just like on a dict, call *t*.get('foo', default=**None**) to get the value of the default argument instead of an exception.

A few attributes, such as class, are defined in the HTML standard as being able to have multiple values (e.g., <body class="foo bar">...</body>). In these cases, the indexing returns a list of values—for example, soup.body['class'] would be ['foo', 'bar'] (again, you get a KeyError exception when the attribute isn't present at all; use the get method, instead of indexing, to get a default value instead).

To get a dict that maps attribute names to values (or, in a few cases defined in the HTML standard, lists of values), use the attribute *t*.attrs:

```
>>> s = bs4.BeautifulSoup('<p foo="bar" class="ic">baz')
>>> s.get('foo')
>>> s.p.get('foo')

'bar'

>>> s.p.attrs

{'foo': 'bar', 'class': ['ic']}
```

How to Check if a Tag Instance Has a Certain Attribute

To check if a `Tag` instance *t*'s HTML attributes include one named `'foo'`, *don't* use `if 'foo' in t:`—the `in` operator on `Tag` instances looks among the `Tag`'s *children*, *not* its *attributes*. Rather, use `if 'foo' in t.attrs:` or, better, `if t.has_attr('foo'):`.

Getting an actual string

When you have an instance of `NavigableString`, you often want to access the actual text string it contains. When you have an instance of `Tag`, you may want to access the unique string it contains, or, should it contain more than one, all of them—perhaps with their text stripped of any whitespace surrounding it. Here's how you can best accomplish these tasks.

When you have a `NavigableString` instance *s* and you need to stash or process its text somewhere, without further navigation on it, call `str(s)`. Or, use `s.encode(codec='utf8')` to get a bytestring, or `s.decode()` to get a text string (i.e., Unicode). These give you the actual string, without references to the `BeautifulSoup` tree that would impede garbage collection (*s* supports all methods of Unicode strings, so call those directly if they do all that you need).

Given an instance *t* of `Tag` containing a single `NavigableString` instance *s*, you can use `t.string` to fetch *s* (or, to just get the text you want from *s*, use `t.string.decode()`). `t.string` only works when *t* has a single child that's a `NavigableString`, or a single child that's a `Tag` whose only child is a `NavigableString`; otherwise, `t.string` is **`None`**.

As an iterator on *all* contained (navigable) strings, use `t.strings`. You can use `''.join(t.strings)` to get all the strings concatenated into one, in a single step. To ignore whitespace around each contained string, use the iterator `t.stripped_strings` (which also skips all-whitespace strings).

Alternatively, call `t.get_text()`: this returns a single (Unicode) string with all the text in *t*'s descendants, in tree order (equivalent to accessing the attribute `t.text`). You can optionally pass, as the only positional argument, a string to use as separator. The default is the empty string, `''`. Pass the named parameter `strip=True` to have each string stripped of surrounding whitespace and all-whitespace strings skipped.

The following examples demonstrate these methods for getting strings from within tags:

```
>>> soup = bs4.BeautifulSoup('<p>Plain <b>bold</b></p>')
>>> print(soup.p.string)

None

>>> print(soup.p.b.string)

bold
```

```
>>> print(''.join(soup.strings))
Plain bold
>>> print(soup.get_text())
Plain bold
>>> print(soup.text)
Plain bold
>>> print(soup.get_text(strip=True))
Plainbold
```


Attribute references on instances of BeautifulSoup and Tag

The simplest, most elegant way to navigate down an HTML tree or subtree in `bs4` is to use Python's attribute reference syntax (as long as each tag you name is unique, or you care only about the first tag so named at each level of descent).

Given any instance *`t`* of `Tag`, a construct like *`t`*`.foo.bar` looks for the first tag `foo` within *`t`*'s descendants and gets a `Tag` instance *`ti`* for it, then looks for the first tag `bar` within *`ti`*'s descendants and returns a `Tag` instance for the `bar` tag.

It's a concise, elegant way to navigate down the tree, when you know there's a single occurrence of a certain tag within a navigable instance's descendants, or when the first occurrence of several is all you care about. But beware: if any level of lookup doesn't find the tag it's looking for, the attribute reference's value is **`None`**, and then any further attribute reference raises `AttributeError`.

Beware of Typos in Attribute References on Tag Instances

Due to this `BeautifulSoup` behavior, any typo you make in an attribute reference on a `Tag` instance gives a value of **`None`**, not an `AttributeError` exception—so, be especially careful!

`bs4` also offers more general ways to navigate down, up, and sideways along the tree. In particular, each navigable class instance has attributes that identify a single "relative" or, in plural form, an iterator over all relatives of that ilk.

contents, children, and descendants

Given an instance *`t`* of `Tag`, you can get a list of all of its children as *`t`*`.contents`, or an iterator on all children as *`t`*`.children`. For an iterator on all *descendants* (children, children of children, and so on), use *`t`*`.descendants`:

```
>>> soup = bs4.BeautifulSoup('<p>Plain <b>bold</b></p>')
>>> list(t.name for t in soup.p.children)
[None, 'b']
```

```
>>> list(t.name for t in soup.p.descendants)
[None, 'b', None]
```

The names that are None correspond to the NavigableString nodes; only the first one of them is a *child* of the p tag, but both are *descendants* of that tag.

parent and parents

Given an instance *n* of any navigable class, its parent node is *n*.parent:

```
>>> soup = bs4.BeautifulSoup('<p>Plain <b>bold</b></p>')
>>> soup.b.parent.name
'p'
```

An iterator on all ancestors, going upwards in the tree, is *n*.parents. This includes instances of NavigableString, since they have parents, too. An instance *b* of BeautifulSoup has *b*.parent **None**, and *b*.parents is an empty iterator.

next_sibling, previous_sibling, next_siblings, and previous_siblings

Given an instance *n* of any navigable class, its sibling node to the immediate left is *n*.previous_sibling, and the one to the immediate right is *n*.next_sibling; either or both can be **None** if *n* has no such sibling. An iterator on all left siblings, going leftward in the tree, is *n*.previous_siblings; an iterator on all right siblings, going rightward in the tree, is *n*.next_siblings (either or both iterators can be empty). This includes instances of NavigableString, since they have siblings, too. For an instance *b* of BeautifulSoup, *b*.previous_sibling and *b*.next_sibling are both **None**, and both of its sibling iterators are empty:

```
>>> soup = bs4.BeautifulSoup('<p>Plain <b>bold</b></p>')
>>> soup.b.previous_sibling, soup.b.next_sibling
('Plain ', None)
```

next_element, previous_element, next_elements, and previous_elements

Given an instance *n* of any navigable class, the node parsed just before it is *n*.previous_element, and the one parsed just after it is *n*.next_element; either or both can be **None** when *n* is the first or last node parsed, respectively. An iterator on all previous elements, going backward in the tree, is *n*.previous_elements; an iterator on all following elements, going forward in the tree, is *n*.next_elements (either or both iterators can be empty). Instances of NavigableString have such attributes, too. For an instance *b* of BeautifulSoup, *b*.previous_element and *b*.next_element are both **None**, and both of its element iterators are empty:

```
>>> soup = bs4.BeautifulSoup('<p>Plain <b>bold</b></p>')
>>> soup.b.previous_element, soup.b.next_element
('Plain ', 'bold')
```

As shown in the previous example, the `b` tag has no `next_sibling` (since it's the last child of its parent); however, it does have a `next_element` (the node parsed just after it, which in this case is the `'bold'` string it contains).

bs4 find… Methods (aka Search Methods)

Each navigable class in `bs4` offers several methods whose names start with `find`, known as *search methods*, to locate tree nodes that satisfy specified conditions.

Search methods come in pairs—one method of each pair walks all the relevant parts of the tree and returns a list of nodes satisfying the conditions, while the other one stops and returns a single node satisfying all the conditions as soon as it finds it (or **`None`** when it finds no such node). Calling the latter method is therefore like calling the former one with argument `limit=1`, then indexing the resulting one-item list to get its single item, but faster and more elegant.

So, for example, for any `Tag` instance *`t`* and any group of positional and named arguments represented by `...`, the following equivalence always holds:

```
just_one = t.find(...)
other_way_list = t.find_all(..., limit=1)
other_way = other_way_list[0] if other_way_list else None
assert just_one == other_way
```

The method pairs are listed in Table 22-2.

Table 22-2. `bs4` `find...` method pairs

`find`, `find_all`	*`b`*`.find(...)`, *`b`*`.find_all(...)` Searches the *descendants* of *b* or, when you pass named argument `recursive=`**`False`** (available only for these two methods, not for other search methods), *b*'s *children* only. These methods are not available on `NavigableString` instances, since they have no descendants; all other search methods are available on `Tag` and `NavigableString` instances. Since `find_all` is frequently needed, `bs4` offers an elegant shortcut: calling a tag is like calling its `find_all` method. In other words, when *b* is a `Tag`, *`b`*`(...)` is the same as *`b`*`.find_all(...)`. Another shortcut, already mentioned in "Attribute references on instances of BeautifulSoup and Tag" on page 629, is that *`b`*`.foo.bar` is like *`b`*`.find('foo').find('bar')`.
`find_next`, `find_all_next`	*`b`*`.find_next(...)`, *`b`*`.find_all_next(...)` Searches the `next_elements` of *b*.
`find_next_sibling`, `find_next_siblings`	*`b`*`.find_next_sibling(...)`, *`b`*`.find_next_siblings(...)` Searches the `next_siblings` of *b*.

Structured Text: HTML

`find_parent`, `find_parents`	*`b`*`.find_parent(...)`, *`b`*`.find_parents(...)` Searches the `parents` of *b*.
`find_previous`, `find_all_previous`	*`b`*`.find_previous(...)`, *`b`*`.find_all_previous(...)` Searches the `previous_elements` of *b*.
`find_previous_sibling`, `find_previous_siblings`	*`b`*`.find_previous_sibling(...)`, *`b`*`.find_previous_siblings(...)` Searches the `previous_siblings` of *b*.

Arguments of search methods

Each search method has three optional arguments: *`name`*, *`attrs`*, and *`string`*. *`name`* and *`string`* are *filters*, as described in the following subsection; *`attrs`* is a `dict`, as described later in this section. In addition, as mentioned in Table 22-2, `find` and `find_all` only (not the other search methods) can optionally be called with the named argument `recursive=`**`False`**, to limit the search to children, rather than all descendants.

Any search method returning a `list` (i.e., one whose name is plural or starts with `find_all`) can optionally take the named argument `limit`: its value, if any, is an integer, putting an upper bound on the length of the `list` it returns (when you pass `limit`, the returned `list` result is truncated if necessary).

After these optional arguments, each search method can optionally have any number of arbitrary named arguments: the argument name can be any identifier (except the name of one of the search method's specific arguments), while the value is a filter.

Filters A *filter* is applied against a *target* that can be a tag's name (when passed as the *`name`* argument), a `Tag`'s `string` or a `NavigableString`'s textual content (when passed as the *`string`* argument), or a `Tag`'s attribute (when passed as the value of a named argument, or in the *`attrs`* argument). Each filter can be:

A Unicode string
: The filter succeeds when the string exactly equals the target.

A bytestring
: It's decoded to Unicode using `utf-8`, and the filter succeeds when the resulting Unicode string exactly equals the target.

A regular expression object (as produced by `re.compile`, covered in "Regular Expressions and the re Module" on page 305)
: The filter succeeds when the `search` method of the RE, called with the target as the argument, succeeds.

A list of strings
: The filter succeeds if any of the strings exactly equals the target (if any of the strings are bytestrings, they're decoded to Unicode using `utf-8`).

A function object
: The filter succeeds when the function, called with the `Tag` or `NavigableString` instance as the argument, returns `True`.

`True`
: The filter always succeeds.

As a synonym of "the filter succeeds," we also say "the target matches the filter."

Each search method finds all relevant nodes that match all of its filters (that is, it implicitly performs a logical **`and`** operation on its filters on each candidate node). (Don't confuse this logic with that of a specific filter having a `list` as an argument value. That one filter matches when any of the items in the `list` do; that is, the filter implicitly performs a logical **`or`** operation on the items of the `list` that is its argument value.)

name To look for `Tags` whose `name` matches a filter, pass the filter as the first positional argument to the search method, or pass it as `name=`*`filter`*:

```
# return all instances of Tag 'b' in the document
soup.find_all('b') # or soup.find_all(name='b')

# return all instances of Tags 'b' and 'bah' in the document
soup.find_all(['b', 'bah'])

# return all instances of Tags starting with 'b' in the document
soup.find_all(re.compile(r'^b'))

# return all instances of Tags including string 'bah' in the document
soup.find_all(re.compile(r'bah'))

# return all instances of Tags whose parent's name is 'foo'
def child_of_foo(tag):
    return tag.parent.name == 'foo'

soup.find_all(child_of_foo)
```

string To look for `Tag` nodes whose `.string`'s text matches a filter, or `NavigableString` nodes whose text matches a filter, pass the filter as `string=`*`filter`*:

```
# return all instances of NavigableString whose text is 'foo'
soup.find_all(string='foo')

# return all instances of Tag 'b' whose .string's text is 'foo'
soup.find_all('b', string='foo')
```

attrs To look for Tag nodes that have attributes whose values match filters, use a dict *d* with attribute names as keys, and filters as the corresponding values. Then, pass *d* as the second positional argument to the search method, or pass attrs=*d*.

As a special case, you can use, as a value in *d*, **None** instead of a filter; this matches nodes that *lack* the corresponding attribute.

As a separate special case, if the value *f* of attrs is not a dict, but a filter, that is equivalent to having attrs={'class': *f*}. (This convenient shortcut helps because looking for tags with a certain CSS class is a frequent task.)

You cannot apply both special cases at once: to search for tags without any CSS class, you must explicitly pass attrs={'class': **None**} (i.e., use the first special case, but not at the same time as the second one):

```
# return all instances of Tag 'b' w/an attribute 'foo' and no 'bar'
soup.find_all('b', {'foo': True, 'bar': None})
```

Matching Tags with Multiple CSS Classes

Unlike most attributes, a tag's 'class' attribute can have multiple values. These are shown in HTML as a space-separated string (e.g., '<p class='foo bar baz'>...'), and in bs4 as a list of strings (e.g., *t*['class'] being ['foo', 'bar', 'baz']).

When you filter by CSS class in any search method, the filter matches a tag if it matches *any* of the multiple CSS classes of such a tag.

To match tags by multiple CSS classes, you can write a custom function and pass it as the filter to the search method; or, if you don't need other added functionality of search methods, you can eschew search methods and instead use the method *t*.select, covered in the following section, and go with the syntax of CSS selectors.

Other named arguments Named arguments, beyond those whose names are known to the search method, are taken to augment the constraints, if any, specified in attrs. For example, calling a search method with *foo*=*bar* is like calling it with attrs={'*foo*': *bar*}.

bs4 CSS Selectors

bs4 tags supply the methods select and select_one, roughly equivalent to find_all and find but accepting as the single argument a string that is a CSS selector and returning, respectively, the list of Tag nodes satisfying that selector or the first such Tag node. For example:

```
def foo_child_of_bar(t):
    return t.name=='foo' and t.parent and t.parent.name=='bar'

# return tags with name 'foo' children of tags with name 'bar'
soup.find_all(foo_child_of_bar)

# equivalent to using find_all(), with no custom filter function needed
soup.select('bar > foo')
```

`bs4` supports only a subset of the rich CSS selector functionality, and we do not cover CSS selectors further in this book. (For complete coverage of CSS, we recommend O'Reilly's *CSS: The Definitive Guide*, by Eric Meyer and Estelle Weyl.) In most cases, the search methods covered in the previous section are better choices; however, in a few special cases, calling `select` can save you the (small) trouble of writing a custom filter function.

An HTML Parsing Example with BeautifulSoup

The following example uses `bs4` to perform a typical task: fetch a page from the web, parse it, and output the HTTP hyperlinks in the page:

```
import urllib.request, urllib.parse, bs4

f = urllib.request.urlopen('http://www.python.org')
b = bs4.BeautifulSoup(f)

seen = set()
for anchor in b('a'):
    url = anchor.get('href')
    if url is None or url in seen:
        continue
    seen.add(url)
    pieces = urllib.parse.urlparse(url)
    if pieces[0].startswith('http'):
        print(urllib.parse.urlunparse(pieces))
```

We first call the instance of class `bs4.BeautifulSoup` (equivalent to calling its `find_all` method) to obtain all instances of a certain tag (here, tag `'<a>'`), then the `get` method of instances of the tag in question to obtain the value of an attribute (here, `'href'`), or **`None`** when that attribute is missing.

Generating HTML

Python does not come with tools specifically meant to generate HTML, nor with ones that let you embed Python code directly within HTML pages. Development and maintenance are eased by separating logic and presentation issues through *templating*, covered in "Templating" on page 638. An alternative is to use `bs4` to create HTML documents in your Python code by gradually altering very minimal initial documents. Since these alterations rely on `bs4` *parsing* some HTML, using different parsers affects the output, as mentioned in "Which parser BeautifulSoup uses" on page 625.

Editing and Creating HTML with bs4

You have various options for editing an instance *t* of `Tag`. You can alter the tag name by assigning to `t.name`, and you can alter *t*'s attributes by treating *t* as a mapping: assign to an indexing to add or change an attribute, or delete the indexing to remove an attribute (for example, **`del`** `t['foo']` removes the attribute `foo`). If you assign some `str` to `t.string`, all previous `t.contents` (`Tags` and/or strings —the whole subtree of *t*'s descendants) are discarded and replaced with a new `NavigableString` instance with that `str` as its textual content.

Given an instance *s* of `NavigableString`, you can replace its textual content: calling `s.replace_with('other')` replaces *s*'s text with `'other'`.

Building and adding new nodes

Altering existing nodes is important, but creating new ones and adding them to the tree is crucial for building an HTML document from scratch.

To create a new `NavigableString` instance, call the class with the text content as the single argument:

```
s = bs4.NavigableString(' some text ')
```

To create a new `Tag` instance, call the `new_tag` method of a `BeautifulSoup` instance, with the tag name as the single positional argument and (optionally) named arguments for attributes:

```
>>> soup = bs4.BeautifulSoup()
>>> t = soup.new_tag('foo', bar='baz')
>>> print(t)

<foo bar="baz"></foo>
```

To add a node to the children of a `Tag`, use the `Tag`'s `append` method. This adds the node after any existing children:

```
>>> t.append(s)
>>> print(t)

<foo bar="baz"> some text </foo>
```

If you want the new node to go elsewhere than at the end, at a certain index among *t*'s children, call `t.insert(n, s)` to put *s* at index *n* in `t.contents` (`t.append` and `t.insert` work as if *t* is a list of its children).

If you have a navigable element *b* and want to add a new node *x* as *b*'s `previous_sibling`, call `b.insert_before(x)`. If instead you want *x* to become *b*'s `next_sibling`, call `b.insert_after(x)`.

If you want to wrap a new parent node *t* around *b*, call *b*.wrap(*t*) (which also returns the newly wrapped tag). For example:

```
>>> print(t.string.wrap(soup.new_tag('moo', zip='zaap')))
<moo zip="zaap"> some text </moo>
>>> print(t)
<foo bar="baz"><moo zip="zaap"> some text </moo></foo>
```

Replacing and removing nodes

You can call *t*.replace_with on any tag *t*: the call replaces *t*, and all its previous contents, with the argument, and returns *t* with its original contents. For example:

```
>>> soup = bs4.BeautifulSoup(
...         '<p>first <b>second</b> <i>third</i></p>', 'lxml')
>>> i = soup.i.replace_with('last')
>>> soup.b.append(i)
>>> print(soup)
<html><body><p>first <b>second<i>third</i></b> last</p></body></html>
```

You can call *t*.unwrap on any tag *t*: the call replaces *t* with its contents, and returns *t* "emptied" (that is, without contents). For example:

```
>>> empty_i = soup.i.unwrap()
>>> print(soup.b.wrap(empty_i))
<i><b>secondthird</b></i>
>>> print(soup)
<html><body><p>first <i><b>secondthird</b></i> last</p></body></html>
```

t.clear removes *t*'s contents, destroys them, and leaves *t* empty (but still in its original place in the tree). *t*.decompose removes and destroys both *t* itself, and its contents:

```
>>> # remove everything between <i> and </i> but leave tags
>>> soup.i.clear()
>>> print(soup)
<html><body><p>first <i></i> last</p></body></html>
>>> # remove everything between <p> and </p> incl. tags
>>> soup.p.decompose()
>>> print(soup)
<html><body></body></html>
>>> # remove <body> and </body>
>>> soup.body.decompose()
>>> print(soup)
<html></html>
```

Structured Text: HTML

Lastly, *t*.extract extracts and returns *t* and its contents, but does not destroy anything.

Building HTML with bs4

Here's an example of how to use bs4's methods to generate HTML. Specifically, the following function takes a sequence of "rows" (sequences) and returns a string that's an HTML table to display their values:

```
def mktable_with_bs4(seq_of_rows):
    tabsoup = bs4.BeautifulSoup('<table>')
    tab = tabsoup.table
    for row in seq_of_rows:
        tr = tabsoup.new_tag('tr')
        tab.append(tr)
        for item in row:
            td = tabsoup.new_tag('td')
            tr.append(td)
            td.string = str(item)
    return tab
```

Here is an example using the function we just defined:

```
>>> example = (
...     ('foo', 'g>h', 'g&h'),
...     ('zip', 'zap', 'zop'),
... )
>>> print(mktable_with_bs4(example))
```

```
<table><tr><td>foo</td><td>g&gt;h</td><td>g&amp;h</td></tr>
<tr><td>zip</td><td>zap</td><td>zop</td></tr></table>
```

Note that bs4 automatically converts markup characters such as <, >, and & to their corresponding HTML entities; for example, 'g>h' renders as 'g>h'.

Templating

To generate HTML, the best approach is often *templating*. You start with a *template* —a text string (often read from a file, database, etc.) that is almost valid HTML, but includes markers, known as *placeholders*, where dynamically generated text must be inserted—and your program generates the needed text and substitutes it into the template.

In the simplest case, you can use markers of the form {*name*}. Set the dynamically generated text as the value for key '*name*' in some dictionary *d*. The Python string formatting method .format (covered in "String Formatting" on page 287) lets you do the rest: when *t* is the template string, *t*.format(*d*) is a copy of the template with all values properly substituted.

In general, beyond substituting placeholders, you'll also want to use conditionals, perform loops, and deal with other advanced formatting and presentation tasks; in the spirit of separating "business logic" from "presentation issues," you'd prefer it if all of the latter were part of your templating. This is where dedicated third-party templating packages come in. There are many of them, but all of this book's authors, having used and authored some in the past, currently prefer `jinja2`, covered next.

The jinja2 Package

For serious templating tasks, we recommend `jinja2` (available on PyPI, like other third-party Python packages, so, easily installable with **`pip install jinja2`**).

The `jinja2` docs are excellent and thorough, covering the templating language itself (conceptually modeled on Python, but with many differences to support embedding it in HTML, and the peculiar needs specific to presentation issues); the API your Python code uses to connect to `jinja2`, and expand or extend it if necessary; as well as other issues, from installation to internationalization, from sandboxing code to porting from other templating engines—not to mention, precious tips and tricks.

In this section, we cover only a tiny subset of `jinja2`'s power, just what you need to get started after installing it. We earnestly recommend studying `jinja2`'s docs to get the huge amount of extra, useful information they effectively convey.

The jinja2.Environment class

When you use `jinja2`, there's always an `Environment` instance involved—in a few cases you could let it default to a generic "shared environment," but that's not recommended. Only in very advanced usage, when you're getting templates from different sources (or with different templating language syntax), would you ever define multiple environments—usually, you instantiate a single `Environment` instance *`env`*, good for all the templates you need to render.

You can customize *`env`* in many ways as you build it, by passing named arguments to its constructor (including altering crucial aspects of templating language syntax, such as which delimiters start and end blocks, variables, comments, etc.). The one named argument you'll almost always pass in real-life use is `loader` (the others are rarely set).

An environment's `loader` specifies where to load templates from, on request—usually some directory in a filesystem, or perhaps some database (you'd have to code a custom subclass of `jinja2.Loader` for the latter purpose), but there are other possibilities. You need a `loader` to let templates enjoy some of `jinja2`'s most powerful features, such as *template inheritance*.

You can equip *`env`*, as you instantiate it, with custom filters, tests, extensions, and so on (each of those can also be added later).

In the examples presented later, we assume *`env`* was instantiated with nothing but `loader=jinja2.FileSystemLoader('`*`/path/to/templates`*`')`, and not further enriched—in fact, for simplicity, we won't even make use of the `loader` argument.

env.get_template(*name*) fetches, compiles, and returns an instance of jinja2.Template based on what env.loader(*name*) returns. In the examples at the end of this section, for simplicity, we'll instead use the rarely warranted env.from_string(*s*) to build an instance of jinja2.Template from string *s*.

The jinja2.Template class

An instance *t* of jinja2.Template has many attributes and methods, but the one you'll be using almost exclusively in real life is:

render	*t*.render(...*context*...) The *context* argument(s) are the same you might pass to a dict constructor—a mapping instance, and/or named arguments enriching and potentially overriding the mapping's key-to-value connections. *t*.render(*context*) returns a (Unicode) string resulting from the *context* arguments applied to the template *t*.

Building HTML with jinja2

Here's an example of how to use a jinja2 template to generate HTML. Specifically, just like in "Building HTML with bs4" on page 638, the following function takes a sequence of "rows" (sequences) and returns an HTML table to display their values:

```
TABLE_TEMPLATE = '''\
<table>
{% for s in s_of_s %}
  <tr>
  {% for item in s %}
    <td>{{item}}</td>
  {% endfor %}
  </tr>
{% endfor %}
</table>'''
def mktable_with_jinja2(s_of_s):
    env = jinja2.Environment(
        trim_blocks=True,
        lstrip_blocks=True,
        autoescape=True)
    t = env.from_string(TABLE_TEMPLATE)
    return t.render(s_of_s=s_of_s)
```

The function builds the environment with option autoescape=**True**, to automatically "escape" strings containing markup characters such as <, >, and &; for example, with autoescape=**True**, 'g>h' renders as 'g>h'.

The options trim_blocks=**True** and lstrip_blocks=**True** are purely cosmetic, just to ensure that both the template string and the rendered HTML string can be nicely formatted; of course, when a browser renders HTML, it does not matter whether the HTML text itself is nicely formatted.

Normally, you would always build the environment with the `loader` argument and have it load templates from files or other storage with method calls such as `t = env.get_template(template_name)`. In this example, just to present everything in one place, we omit the loader and build the template from a string by calling the method `env.from_string` instead. Note that `jinja2` is not HTML- or XML-specific, so its use alone does not guarantee the validity of the generated content, which you should carefully check if standards conformance is a requirement.

The example uses only the two most common features out of the many dozens that the `jinja2` templating language offers: *loops* (that is, blocks enclosed in `{% for ... %}` and `{% endfor %}`) and *parameter substitution* (inline expressions enclosed in `{{` and `}}`).

Here is an example use of the function we just defined:

```
>>> example = (
...   ('foo', 'g>h', 'g&h'),
...   ('zip', 'zap', 'zop'),
... )
>>> print(mktable_with_jinja2(example))
```

```
<table>
  <tr>
    <td>foo</td>
    <td>g&gt;h</td>
    <td>g&amp;h</td>
  </tr>
  <tr>
    <td>zip</td>
    <td>zap</td>
    <td>zop</td>
  </tr>
</table>
```

23
Structured Text: XML

XML, the *eXtensible Markup Language*, is a widely used data interchange format. On top of XML itself, the XML community (in good part within the World Wide Web Consortium, or W3C) has standardized many other technologies, such as schema languages, namespaces, XPath, XLink, XPointer, and XSLT.

Industry consortia have additionally defined industry-specific markup languages on top of XML for data exchange among applications in their respective fields. XML, XML-based markup languages, and other XML-related technologies are often used for inter-application, cross-language, cross-platform data interchange in specific fields.

Python's standard library, for historical reasons, has multiple modules supporting XML under the `xml` package, with overlapping functionality; this book does not cover them all, but interested readers can find details in the online documentation.

This book (and, specifically, this chapter) covers only the most Pythonic approach to XML processing: `ElementTree`, created by the deeply missed Fredrik Lundh, best known as "the effbot."[1] Its elegance, speed, generality, multiple implementations, and Pythonic architecture make this the package of choice for Python XML applications. For tutorials and complete details on the `xml.etree.ElementTree` module beyond what this chapter provides, see the online docs. This book takes for granted some elementary knowledge of XML itself; if you need to learn more about XML, we recommend *XML in a Nutshell* by Elliotte Rusty Harold and W. Scott Means (O'Reilly).

1 Alex is far too modest to mention it, but from around 1995 to 2005 both he and Fredrik were, along with Tim Peters, *the* Python bots. Known as such for their encyclopedic and detailed knowledge of the language, the effbot, the martellibot, and the timbot have created software and documentation that are of immense value to millions of people.

Parsing XML from untrusted sources puts your application at risk of many possible attacks. We do not cover this issue specifically, but the online documentation recommends third-party modules to help safeguard your application if you do have to parse XML from sources you can't fully trust. In particular, if you need an `ElementTree` implementation with safeguards against parsing untrusted sources, consider `defusedxml.ElementTree`.

ElementTree

Python and third-party add-ons offer several alternative implementations of the `ElementTree` functionality; the one you can always rely on in the standard library is the module `xml.etree.ElementTree`. Just importing `xml.etree.ElementTree` gets you the fastest implementation available in your Python installation's standard library. The third-party package `defusedxml`, mentioned in this chapter's introduction, offers slightly slower but safer implementations if you ever need to parse XML from untrusted sources; another third-party package, `lxml`, gets you faster performance, and some extra functionality, via `lxml.etree`.

Traditionally, you get whatever available implementation of `ElementTree` you prefer using a **`from...import...as`** statement such as this:

```
from xml.etree import ElementTree as et
```

Or this, which tries to import `lxml` and, if unable, falls back to the version provided in the standard library:

```
try:
    from lxml import etree as et
except ImportError:
    from xml.etree import ElementTree as et
```

Once you succeed in importing an implementation, use it as `et` (some prefer the uppercase variant, `ET`) in the rest of your code.

`ElementTree` supplies one fundamental class representing a *node* within the *tree* that naturally maps an XML document: the class `Element`. `ElementTree` also supplies other important classes, chiefly the one representing the whole tree, with methods for input and output and many convenience classes equivalent to ones on its `Element` *root*—that's the class `ElementTree`. In addition, the `ElementTree` module supplies several utility functions, and auxiliary classes of lesser importance.

The Element Class

The `Element` class represents a node in the tree that maps an XML document, and it's the core of the whole `ElementTree` ecosystem. Each element is a bit like a mapping, with *attributes* that map string keys to string values, and also a bit like a sequence, with *children* that are other elements (sometimes referred to as the element's "subelements"). In addition, each element offers a few extra attributes and methods. Each `Element` instance *e* has four data attributes or properties, detailed in Table 23-1.

Table 23-1. Attributes of an `Element` instance e

attrib	A dict containing all of the XML node's attributes, with strings, the attributes' names, as its keys (and, usually, strings as corresponding values as well). For example, parsing the XML fragment bc, you get an *e* whose *e*.attrib is {'x': 'y'}.

Avoid Accessing attrib on Element Instances

It's normally best to avoid accessing *e*.attrib when possible, because the implementation might need to build it on the fly when you access it. *e* itself offers some typical mapping methods (listed in Table 23-2) that you might otherwise want to call on *e*.attrib; going through *e*'s own methods allows an implementation to optimize things for you, compared to the performance you'd get via the actual dict *e*.attrib.

tag	The XML tag of the node: a string, sometimes also known as the element's *type*. For example, parsing the XML fragment bc, you get an *e* with *e*.tag set to 'a'.
tail	Arbitrary data (a string) immediately "following" the element. For example, parsing the XML fragment bc, you get an *e* with *e*.tail set to 'c'.
text	Arbitrary data (a string) directly "within" the element. For example, parsing the XML fragment bc, you get an *e* with *e*.text set to 'b'.

e has some methods that are mapping-like and avoid the need to explicitly ask for the *e*.attrib dict. These are listed in Table 23-2.

Table 23-2. Mapping-like methods of an `Element` instance e

clear	*e*.clear() Leaves *e* "empty," except for its tag, removing all attributes and children, and setting text and tail to **None**.
get	*e*.get(*key*, default=**None**) Like *e*.attrib.get(*key*, *default*), but potentially much faster. You cannot use *e*[*key*], since indexing on *e* is used to access children, not attributes.
items	*e*.items() Returns the list of (*name*, *value*) tuples for all attributes, in arbitrary order.
keys	*e*.keys() Returns the list of all attribute names, in arbitrary order.
set	*e*.set(*key*, *value*) Sets the value of the attribute named *key* to *value*.

The other methods of *e* (including methods for indexing with the `e[i]` syntax and for getting the length, as in `len(e)`) deal with all of *e*'s children as a sequence, or in some cases—indicated in the rest of this section—with all descendants (elements in the subtree rooted at *e*, also known as subelements of *e*).

Don't Rely on Implicit bool Conversion of an Element

In all versions up through Python 3.11, an `Element` instance *e* evaluates as false if *e* has no children, following the normal rule for Python containers' implicit `bool` conversion. However, it is documented that this behavior may change in some future version of Python. For future compatibility, if you want to check whether *e* has no children, explicitly check `if len(e) == 0:` instead of using the normal Python idiom `if not e:`.

The named methods of *e* dealing with children or descendants are listed in Table 23-3 (we do not cover XPath in this book: see the online docs for information on that topic). Many of the following methods take an optional argument `namespaces`, defaulting to **None**. When present, `namespaces` is a mapping with XML namespace prefixes as keys and corresponding XML namespace full names as values.

Table 23-3. Methods of an `Element` instance e dealing with children or descendants

`append`	`e.append(se)` Adds subelement *se* (which must be an `Element`) at the end of *e*'s children.
`extend`	`e.extend(ses)` Adds each item of iterable *ses* (every item must be an `Element`) at the end of *e*'s children.
`find`	`e.find(match, namespaces=None)` Returns the first descendant matching *match*, which may be a tag name or an XPath expression within the subset supported by the current implementation of `ElementTree`. Returns **None** if no descendant matches *match*.
`findall`	`e.findall(match, namespaces=None)` Returns the list of all descendants matching *match*, which may be a tag name or an XPath expression within the subset supported by the current implementation of `ElementTree`. Returns [ ] if no descendants match *match*.
`findtext`	`e.findtext(match, default=None, namespaces=None)` Returns the `text` of the first descendant matching *match*, which may be a tag name or an XPath expression within the subset supported by the current implementation of `ElementTree`. The result may be an empty string, `''`, if the first descendant matching *match* has no `text`. Returns `default` if no descendant matches *match*.
`insert`	`e.insert(index, se)` Adds subelement *se* (which must be an `Element`) at index *index* within the sequence of *e*'s children.

`iter`	`e.iter(tag='*')` Returns an iterator walking in depth-first order over all of *e*'s descendants. When *tag* is not `'*'`, only yields subelements whose `tag` equals *tag*. Don't modify the subtree rooted at *e* while you're looping on *e*`.iter`.
`iterfind`	`e.iterfind(match, namespaces=None)` Returns an iterator over all descendants, in depth-first order, matching *match*, which may be a tag name or an XPath expression within the subset supported by the current implementation of `ElementTree`. The resulting iterator is empty when no descendants match *match*.
`itertext`	`e.itertext(match, namespaces=None)` Returns an iterator over the `text` (not the `tail`) attribute of all descendants, in depth-first order, matching *match*, which may be a tag name or an XPath expression within the subset supported by the current implementation of `ElementTree`. The resulting iterator is empty when no descendants match *match*.
`remove`	`e.remove(se)` Removes the descendant that **is** element *se* (as covered in Table 3-4).

The ElementTree Class

The `ElementTree` class represents a tree that maps an XML document. The core added value of an instance *et* of `ElementTree` is to have methods for wholesale parsing (input) and writing (output) of a whole tree. These methods are described in Table 23-4.

Structured Text: XML

Table 23-4. `ElementTree` instance parsing and writing methods

`parse`	`et.parse(source, parser=None)` *source* can be a file open for reading, or the name of a file to open and read (to parse a string, wrap it in `io.StringIO`, covered in "In-Memory Files: io.StringIO and io.BytesIO" on page 334), containing XML text. *et*`.parse` parses that text, builds its tree of `Element`s as the new content of *et* (discarding the previous content of *et*, if any), and returns the root element of the tree. `parser` is an optional parser instance; by default, *et*`.parse` uses an instance of class `XMLParser` supplied by the `ElementTree` module (this book does not cover `XMLParser`; see the online docs).
`write`	`et.write(file, encoding='us-ascii', xml_declaration=None, default_namespace=None, method='xml', short_empty_elements=True)` *file* can be a file open for writing, or the name of a file to open and write (to write into a string, pass as *file* an instance of `io.StringIO`, covered in "In-Memory Files: io.StringIO and io.BytesIO" on page 334). *et*`.write` writes into that file the text representing the XML document for the tree that is the content of *et*.

`write` *(cont.)*	*`encoding`* should be spelled according to the standard, not by using common "nicknames"—for example, `'iso-8859-1'`, not `'latin-1'`, even though Python itself accepts both spellings for this encoding, and similarly `'utf-8'`, with the dash, not `'utf8'`, without it. The best choice often is to pass `encoding` as `'unicode'`. This outputs text (Unicode) strings, when *`file`*`.write` accepts such strings; otherwise, *`file`*`.write` must accept bytestrings, and that will be the type of strings that *`et`*`.write` outputs, using XML character references for characters not in the encoding—for example, with the default US-ASCII encoding, "e with an acute accent," é, is output as `é`. You can pass `xml_declaration` as **`False`** to not have the declaration in the resulting text, or as **`True`** to have it; the default is to have the declaration in the result only when `encoding` is not one of `'us-ascii'`, `'utf-8'`, or `'unicode'`. You can optionally pass `default_namespace` to set the default namespace for `xmlns` constructs. You can pass `method` as `'text'` to output only the `text` and `tail` of each node (no tags). You can pass `method` as `'html'` to output the document in HTML format (which, for example, omits end tags not needed in HTML, such as `</br>`). The default is `'xml'`, to output in XML format. You can optionally (only by name, not positionally) pass `short_empty_elements` as **`False`** to always use explicit start and end tags, even for elements that have no text or subelements; the default is to use the XML short form for such empty elements. For example, an empty element with tag `a` is output as `<a/>` by default, or as `<a></a>` if you pass `short_empty_elements` as **`False`**.

In addition, an instance *`et`* of `ElementTree` supplies the method `getroot` (to return the root of the tree) and the convenience methods `find`, `findall`, `findtext`, `iter`, and `iterfind`, each exactly equivalent to calling the same method on the root of the tree—that is, on the result of *`et`*`.getroot`.

Functions in the ElementTree Module

The `ElementTree` module also supplies several functions, described in Table 23-5.

Table 23-5. `ElementTree` functions

`Comment`	`Comment(text=`**`None`**`)` Returns an `Element` that, once inserted as a node in an `ElementTree`, will be output as an XML comment with the given `text` string enclosed between `'<!--'` and `'-->'`. `XMLParser` skips XML comments in any document it parses, so this function is the only way to insert comment nodes.
`dump`	`dump(`*`e`*`)` Writes `e`, which can be an `Element` or an `ElementTree`, as XML to `sys.stdout`. This function is meant only for debugging purposes.
`fromstring`	`fromstring(`*`text`*`, parser=`**`None`**`)` Parses XML from the *`text`* string and returns an `Element`, just like the XML function just covered.

fromstring list	`fromstringlist(`*`sequence`*`, parser=`**`None`**`)` Just like `fromstring(''.join(`*`sequence`*`))`, but can be a bit faster by avoiding the `join`.
iselement	`iselement(`*`e`*`)` Returns **`True`** if *`e`* is an `Element`; otherwise, returns **`False`**.
iterparse	`iterparse(`*`source`*`, events=['end'], parser=`**`None`**`)` Parses an XML document and incrementally builds the corresponding `ElementTree`. *`source`* can be a file open for reading, or the name of a file to open and read, containing an XML document as text. `iterparse` returns an iterator yielding two-item tuples `(`*`event`*`, `*`element`*`)`, where *`event`* is one of the strings listed in the argument `events` (each string must be `'start'`, `'end'`, `'start-ns'`, or `'end-ns'`), as the parsing progresses. *`element`* is an `Element` for events `'start'` and `'end'`, **`None`** for event `'end-ns'`, and a tuple of two strings `(`*`namespace_prefix`*`, `*`namespace_uri`*`)` for event `'start-ns'`. `parser` is an optional parser instance; by default, `iterparse` uses an instance of the class `XMLParser` supplied by the `ElementTree` module (see the online docs for details on the `XMLParser` class). The purpose of `iterparse` is to let you iteratively parse a large XML document, without holding all of the resulting `ElementTree` in memory at once, whenever feasible. We cover `iterparse` in more detail in "Parsing XML Iteratively" on page 652.
parse	`parse(`*`source`*`, parser=`**`None`**`)` Just like the `parse` method of `ElementTree`, covered in Table 23-4, except that it returns the `ElementTree` instance it creates.
Processing Instruction	`ProcessingInstruction(`*`target`*`, text=`**`None`**`)` Returns an `Element` that, once inserted as a node in an `ElementTree`, will be output as an XML processing instruction with the given *`target`* and `text` strings enclosed between `'<?'` and `'?>'`. `XMLParser` skips XML processing instructions in any document it parses, so this function is the only way to insert processing instruction nodes.
register_ namespace	`register_namespace(`*`prefix`*`, `*`uri`*`)` Registers the string *`prefix`* as the namespace prefix for the string *`uri`*; elements in the namespace get serialized with this prefix.
SubElement	`SubElement(`*`parent`*`, `*`tag`*`, attrib={}, **`*`extra`*`)` Creates an `Element` with the given *`tag`*, attributes from `dict attrib`, and others passed as named arguments in *`extra`*, and appends it as the rightmost child of `Element` *`parent`*; returns the `Element` it has created.
tostring	`tostring(`*`e`*`, encoding='us-ascii', method='xml', short_empty_elements=`**`True`**`)` Returns a string with the XML representation of the subtree rooted at `Element` *`e`*. Arguments have the same meaning as for the `write` method of `ElementTree`, covered in Table 23-4.
tostring list	`tostringlist(`*`e`*`, encoding='us-ascii', method='xml', short_empty_elements=`**`True`**`)` Returns a list of strings with the XML representation of the subtree rooted at `Element` *`e`*. Arguments have the same meaning as for the `write` method of `ElementTree`, covered in Table 23-4.

`XML`	`XML(text, parser=None)` Parses XML from the *`text`* string and returns an `Element`. `parser` is an optional parser instance; by default, `XML` uses an instance of the class `XMLParser` supplied by the `ElementTree` module (this book does not cover the `XMLParser` class; see the online docs for details).
`XMLID`	`XMLID(text, parser=None)` Parses XML from the *`text`* string and returns a tuple with two items: an `Element` and a `dict` mapping `id` attributes to the only `Element` having each (XML forbids duplicate `ids`). `parser` is an optional parser instance; by default, `XMLID` uses an instance of the class `XMLParser` supplied by the `ElementTree` module (this book does not cover the `XMLParser` class; see the online docs for details).

The `ElementTree` module also supplies the classes `QName`, `TreeBuilder`, and `XMLParser`, which we do not cover in this book, and the class `XMLPullParser`, covered in "Parsing XML Iteratively" on page 652.

Parsing XML with ElementTree.parse

In everyday use, the most common way to make an `ElementTree` instance is by parsing it from a file or file-like object, usually with the module function `parse` or with the method `parse` of instances of the class `ElementTree`.

For the examples in the remainder of this chapter, we use the simple XML file found at *http://www.w3schools.com/xml/simple.xml*; its root tag is `'breakfast_menu'`, and the root's children are elements with the tag `'food'`. Each `'food'` element has a child with the tag `'name'`, whose text is the food's name, and a child with the tag `'calories'`, whose text is the string representation of the integer number of calories in a portion of that food. In other words, a simplified representation of that XML file's content of interest to the examples is:

```
<breakfast_menu>
  <food>
    <name>Belgian Waffles</name>
    <calories>650</calories>
  </food>
  <food>
    <name>Strawberry Belgian Waffles</name>
    <calories>900</calories>
  </food>
  <food>
    <name>Berry-Berry Belgian Waffles</name>
    <calories>900</calories>
  </food>
  <food>
    <name>French Toast</name>
    <calories>600</calories>
  </food>
  <food>
```

```
    <name>Homestyle Breakfast</name>
    <calories>950</calories>
  </food>
</breakfast_menu>
```

Since the XML document lives at a WWW URL, you start by obtaining a file-like object with that content, and passing it to `parse`; the simplest way uses the `urllib.request` module:

```
from urllib import request
from xml.etree import ElementTree as et
content = request.urlopen('http://www.w3schools.com/xml/simple.xml')
tree = et.parse(content)
```

Selecting Elements from an ElementTree

Let's say that we want to print on standard output the calories and names of the various foods, in order of increasing calories, with ties broken alphabetically. Here's the code for this task:

```
def bycal_and_name(e):
    return int(e.find('calories').text), e.find('name').text

for e in sorted(tree.findall('food'), key=bycal_and_name):
    print(f"{e.find('calories').text} {e.find('name').text}")
```

When run, this prints:

```
600 French Toast
650 Belgian Waffles
900 Berry-Berry Belgian Waffles
900 Strawberry Belgian Waffles
950 Homestyle Breakfast
```

Editing an ElementTree

Once an `ElementTree` is built (be that via parsing, or otherwise), you can "edit" it—inserting, deleting, and/or altering nodes (elements)—via various methods of the `ElementTree` and `Element` classes, and module functions. For example, suppose our program is reliably informed that a new food has been added to the menu—buttered toast, two slices of white bread toasted and buttered, 180 calories—while any food whose name contains "berry," case insensitive, has been removed. The "editing the tree" part for these specs can be coded as follows:

```
# add Buttered Toast to the menu
menu = tree.getroot()
toast = et.SubElement(menu, 'food')
tcals = et.SubElement(toast, 'calories')
tcals.text = '180'
tname = et.SubElement(toast, 'name')
tname.text = 'Buttered Toast'
# remove anything related to 'berry' from the menu
for e in menu.findall('food'):
```

```
        name = e.find('name').text
        if 'berry' in name.lower():
            menu.remove(e)
```

Once we insert these "editing" steps between the code parsing the tree and the code selectively printing from it, the latter prints:

```
180 Buttered Toast
600 French Toast
650 Belgian Waffles
950 Homestyle Breakfast
```

The ease of editing an `ElementTree` can sometimes be a crucial consideration, making it worth your while to keep it all in memory.

Building an ElementTree from Scratch

Sometimes, your task doesn't start from an existing XML document: rather, you need to make an XML document from data your code gets from a different source, such as a CSV file or some kind of database.

The code for such tasks is similar to the code we showed for editing an existing `ElementTree`—just add a little snippet to build an initially empty tree.

For example, suppose you have a CSV file, *menu.csv*, whose two comma-separated columns are the calories and names of various foods, one food per row. Your task is to build an XML file, *menu.xml*, similar to the one we parsed in the previous examples. Here's one way you could do that:

```
import csv
from xml.etree import ElementTree as et

menu = et.Element('menu')
tree = et.ElementTree(menu)
with open('menu.csv') as f:
    r = csv.reader(f)
    for calories, namestr in r:
        food = et.SubElement(menu, 'food')
        cals = et.SubElement(food, 'calories')
        cals.text = calories
        name = et.SubElement(food, 'name')
        name.text = namestr

tree.write('menu.xml')
```

Parsing XML Iteratively

For tasks focused on selecting elements from an existing XML document, sometimes you don't need to build the whole `ElementTree` in memory—a consideration that's particularly important if the XML document is very large (not the case for the tiny example document we've been dealing with, but stretch your imagination and visualize a similar menu-focused document that lists millions of different foods).

Suppose we have such a large document, and we want to print on standard output the calories and names of the 10 lowest-calorie foods, in order of increasing calories, with ties broken alphabetically. Our *menu.xml* file, which for simplicity's sake we'll assume is now a local file, lists millions of foods, so we'd rather not keep it all in memory (obviously, we don't need complete access to all of it at once).

The following code represents a naive attempt to parse without building the whole structure in memory:

```
import heapq
from xml.etree import ElementTree as et

def cals_and_name():
    # generator for (calories, name) pairs
    for _, elem in et.iterparse('menu.xml'):
        if elem.tag != 'food':
            continue
        # just finished parsing a food, get calories and name
        cals = int(elem.find('calories').text)
        name = elem.find('name').text
        yield (cals, name)

lowest10 = heapq.nsmallest(10, cals_and_name())

for cals, name in lowest10:
    print(cals, name)
```

This approach does indeed work, but unfortunately it consumes just about as much memory as an approach based on a full `et.parse` would! This is because `iterparse` builds up a whole `ElementTree` in memory, even though it only communicates back events such as (and by default only) `'end'`, meaning "I just finished parsing this element."

To actually save memory, we can at least toss all the contents of each element as soon as we're done processing it—that is, right after the **`yield`**, we can add `elem.clear()` to make the just-processed element empty.

This approach would indeed save some memory—but not all of it, because the tree's root would still end up with a huge list of empty child nodes. To be really frugal in memory consumption, we need to get `'start'` events as well, so we can get hold of the root of the `ElementTree` being built and remove each element from it as it's used, rather than just clearing the element. That is, we want to change the generator into:

```
def cals_and_name():
    # memory-thrifty generator for (calories, name) pairs
    root = None
    for event, elem in et.iterparse('menu.xml', ['start', 'end']):
        if event == 'start':
```

```
    if root is None:
        root = elem
    continue
if elem.tag != 'food':
    continue
# just finished parsing a food, get calories and name
cals = int(elem.find('calories').text)
name = elem.find('name').text
yield (cals, name)
root.remove(elem)
```

This approach saves as much memory as feasible, and still gets the task done!

Parsing XML Within an Asynchronous Loop

While `iterparse`, used correctly, can save memory, it's still not good enough to use within an asynchronous loop. That's because `iterparse` makes blocking `read` calls to the file object passed as its first argument: such blocking calls are a no-no in async processing.

`ElementTree` offers the class `XMLPullParser` to help with this issue; see the online docs for the class's usage pattern.

24

Packaging Programs and Extensions

In this chapter, abridged for print publication, we describe the packaging ecosystem's development. We provide additional material in the online version of this chapter, available in the GitHub repository for this book. Among other topics (see "Online Material" on page 658 for a complete list), in the online version we describe `poetry`, a modern standards-compliant Python build system, and compare it with the more traditional `setuptools` approach.

Suppose you have some Python code that you need to deliver to other people and groups. It works on your machine, but now you have the added complication of making it work for other people. This involves packaging your code in a suitable format and making it available to its intended audience.

The quality and diversity of the Python packaging ecosystem have greatly improved since the last edition, and its documentation is both better organized and much more complete. These improvements are based on careful work to specify a Python source tree format independent of any specific build system in PEP 517, "A Build-System Independent Format for Source Trees," and the minimum build system requirements in PEP 518, "Specifying Minimum Build System Requirements for Python Projects." The "Rationale" section of the latter document concisely describes why these changes were required, the most significant being removal of the need to run the *setup.py* file to discover (presumably by observing tracebacks) the build's requirements.

The major purpose of PEP 517 is to specify the format of build definitions in a file called *pyproject.toml*. The file is organized into sections called *tables*, each with a header comprising the table's name in brackets, much like a config file. Each table contains values for various parameters, consisting of a name, an equals sign, and a value. **3.11+** Python includes the `tomllib` module for extracting these definitions, with `load` and `loads` methods similar to those in the `json` module.[1]

Although more and more tools in the Python ecosystem are using these modern standards, you should still expect to continue to encounter the more traditional `setuptools`-based build system (which is itself transitioning to the *pyproject.toml* base recommended in PEP 517). For an excellent survey of packaging tools available, see the list maintained by the Python Packaging Authority (PyPA).

To explain packaging, we first describe its development, then we discuss `poetry` and `setuptools`. Other PEP 517-compliant build tools worth mentioning include `flit` and `hatch`, and you should expect their number to grow as interoperability continues to improve. For distributing relatively simple pure Python packages, we also introduce the standard library module `zipapp`, and we complete the chapter with a short section explaining how to access data bundled as part of a package.

What We Don't Cover in This Chapter

Apart from the PyPA-sanctioned methods, there are many other possible ways of distributing Python code—far too many to cover in a single chapter. We do not cover the following packaging and distribution topics, which may well be of interest to those wishing to distribute Python code:

- Using `conda`
- Using Docker
- Various methods of creating binary executable files from Python code, such as the following (these tools can be tricky to set up for complex projects, but they repay the effort by widening the potential audience for an application):
  - PyInstaller, which takes a Python application and bundles all the required dependencies (including the Python interpreter and necessary extension libraries) into a single executable program that can be distributed as a standalone application. Versions exist for Windows, macOS, and Linux, though each architecture can only produce its own executable.
  - PyOxidizer, the main tool in a utility set of the same name, which not only allows the creation of standalone executables but can also create Windows and macOS installers and other artifacts.
  - cx_Freeze, which creates a folder containing a Python interpreter, extension libraries, and a ZIP file of the Python code. You can convert this into either a Windows installer or a macOS disk image.

1 Users of older versions can install the library from PyPI with **`pip install toml`**.

A Brief History of Python Packaging

Before the advent of virtual environments, maintaining multiple Python projects and avoiding conflicts between their different dependency requirements was a complex business involving careful management of `sys.path` and the `PYTHONPATH` environment variable. If different projects required the same dependency in two different versions, no single Python environment could support both. Nowadays, each virtual environment (see "Python Environments" on page 237 for a refresher on this topic) has its own *site_packages* directory into which third-party and local packages and modules can be installed in a number of convenient ways, making it largely unnecessary to think about the mechanism.[2]

When the Python Package Index was conceived in 2003, no such features were available, and there was no uniform way to package and distribute Python code. Developers had to carefully adapt their environment to each different project they worked on. This changed with the development of the `distutils` standard library package, soon leveraged by the third-party `setuptools` package and its `easy_install` utility. The now-obsolete platform-independent *egg* packaging format was the first definition of a single-file format for Python package distribution, allowing easy download and installation of eggs from network sources. Installing a package used a *setup.py* component, whose execution would integrate the package's code into an existing Python environment using the features of `setuptools`. Requiring a third-party (i.e., not part of the standard distribution) module such as `setuptools` was clearly not a fully satisfactory solution.

In parallel with these developments came the creation of the `virtualenv` package, vastly simplifying project management for the average Python programmer by offering clean separation between the Python environments used by different projects. Shortly after this, the `pip` utility, again largely based on the ideas behind `setuptools`, was introduced. Using source trees rather than eggs as its distribution format, `pip` could not only install packages but uninstall them as well. It could also list the contents of a virtual environment and accept a versioned list of the project's dependencies, by convention in a file named *requirements.txt*.

`setuptools` development was somewhat idiosyncratic and not responsive to community needs, so a fork named `distribute` was created as a drop-in replacement (it installed under the `setuptools` name), to allow development work to proceed along more collaborative lines. This was eventually merged back into the `setuptools` codebase, which is nowadays controlled by the PyPA: the ability to do this affirmed the value of Python's open source licensing policy.

2 Be aware that some packages are less than friendly to virtual environments. Happily, these are few and far between.

-3.11 The `distutils` package was originally designed as a standard library component to help with installing extension modules (particularly those written in compiled languages, covered in Chapter 25). Although it currently remains in the standard library, it has been deprecated and is scheduled for removal from version 3.12, when it will likely be incorporated into `setuptools`. A number of other tools have emerged that conform to PEPs 517 and 518. In this chapter we'll look at different ways to install additional functionality into a Python environment.

With the acceptance of PEP 425, "Compatibility Tags for Built Distributions," and PEP 427, "The Wheel Binary Package Format," Python finally had a specification for a binary distribution format (the *wheel*, whose definition has since been updated) that would allow the distribution of compiled extension packages for different architectures, falling back to installing from source when no appropriate binary wheel is available.

PEP 453, "Explicit Bootstrapping of pip in Python Installations," determined that the `pip` utility should become the preferred way to install packages in Python, and established a process whereby it could be updated independently of Python to allow new deployment features to be delivered without waiting for new language releases.

These developments and many others that have rationalized the Python ecosystem are due to a lot of hard work by the PyPA, to whom Python's ruling "Steering Council" has delegated most matters relating to packaging and distribution. For a more in-depth and advanced explanation of the material in this chapter, see the "Python Packaging User Guide", which offers sound advice and useful instruction to anyone who wants to make their Python software widely available.

Online Material

As mentioned at the start of the chapter, the online version of this chapter contains additional material. The topics covered are:

- The build process
- Entry points
- Distribution formats
- `poetry`
- `setuptools`
- Distributing your package
- `zipapp`
- Accessing data included with your code

25
Extending and Embedding Classic Python

The content of this chapter has been abbreviated for the print edition of this book. The full content is available online, as described in "Online Material" on page 660.

CPython runs on a portable, C-coded virtual machine. Python's built-in objects—such as numbers, sequences, dictionaries, sets, and files—are coded in C, as are several modules in Python's standard library. Modern platforms support dynamically loaded libraries, with file extensions such as *.dll* on Windows, *.so* on Linux, and *.dylib* on Mac: building Python produces such binary files. You can code your own extension modules for Python in C (or any language that can produce C-callable libraries), using the Python C API covered in this chapter. With this API, you can produce and deploy dynamic libraries that Python scripts and interactive sessions can later use with the **import** statement, covered in "The import Statement" on page 222.

Extending Python means building modules that Python code can **import** to access the features the modules supply. *Embedding* Python means executing Python code from an application coded in another language. For such execution to be useful, Python code must in turn be able to access some of your application's functionality. In practice, therefore, embedding implies some extending, as well as a few embedding-specific operations. The three main reasons for wishing to extend Python can be summarized as follows:

- Reimplementing some functionality (originally coded in Python) in a lower-level language, hoping to get better performance
- Letting Python code access some existing functionality supplied by libraries coded in (or, at any rate, callable from) lower-level languages

- Letting Python code access some existing functionality of an application that is in the process of embedding Python as the application's scripting language

Embedding and extending are covered in Python's online documentation; there, you can find an in-depth tutorial and an extensive reference manual. Many details are best studied in Python's extensively documented C sources. Download Python's source distribution and study the sources of Python's core, C-coded extension modules, and the example extensions supplied for this purpose.

Online Material

> **This Chapter Assumes Some Knowledge of C**
> Although we include some non-C extension options, to extend or embed Python using the C API you must know the C and/or C++ programming languages. We do not cover C and C++ in this book, but there are many print and online resources that you can consult to learn them. Most of the online content of this chapter assumes that you have at least some knowledge of C.

In the online version of this chapter, you will find the following sections:

"Extending Python with Python's C API"
: Includes reference tables and examples for creating C-coded Python extension modules that you can import into your Python programs, showing how to code and build such modules. This section includes two complete examples:

  - An extension implementing custom methods for manipulating `dicts`
  - An extension defining a custom type

"Extending Python Without Python's C API"
: Discusses (or, at least, mentions and links to) several utilities and libraries that support creating Python extensions that do not directly require C or C++ programming,[1] including the third-party tools F2PY, SIP, CLIF, `cppyy`, `pybind11`, Cython, CFFI, and HPy, and standard library module `ctypes`. This section includes a complete example on how to create an extension using Cython.

"Embedding Python"
: Includes reference tables and a conceptual overview of embedding a Python interpreter within a larger application, using Python's C API for embedding.

1 There are many other such tools, but we tried to pick just the most popular and promising ones.

26

v3.7 to v3.n Migration

This book spans several versions of Python and covers some substantial (and still evolving!) new features, including:

- Order-preserving `dicts`
- Type annotations
- `:=` assignment expressions (informally called "the walrus operator")
- Structural pattern matching

Individual developers may be able to install each new Python version as it is released, and solve compatibility issues as they go. But for Python developers working in a corporate environment or maintaining a shared library, migrating from one version to the next involves deliberation and planning.

This chapter deals with the changing shape of the Python language, as seen from a Python programmer's viewpoint. (There have been many changes in Python internals as well, including to the Python C API, but those are beyond the scope of this chapter: for details, see the "What's New in Python 3.*n*" sections of each release's online documentation.)

Significant Changes in Python Through 3.11

Most releases have a handful of significant new features and improvements that characterize that release, and it is useful to have these in mind as high-level reasons for targeting a particular release. Table 26-1 details only major new features and breaking changes in versions 3.6–3.11[1] that are likely to affect many Python programs; see the Appendix for a more complete list.

Table 26-1. Significant changes in recent Python releases

Version	New features	Breaking changes
3.6	• `dicts` preserve order (as an implementation detail of CPython) • F-strings added • _ in numeric literals supported • Annotations can be used for types, which can be checked with external tools such as `mypy` • `asyncio` is no longer a provisional module *Initial release: December 2016* *End of support: December 2021*	• Unknown escapes of \ and an ASCII letter no longer supported in pattern arguments to most `re` functions (still permitted in `re.sub()` only)
3.7	• `dicts` preserve order (as a formal language guarantee) • `dataclasses` module added • `breakpoint()` function added *Initial release: June 2018* *Planned end of support: June 2023*	• Unknown escapes of \ and an ASCII letter no longer supported in pattern arguments to `re.sub()` • Named arguments no longer supported in `bool()`, `float()`, `list()`, and `tuple()` • Leading named argument in `int()` no longer supported

1 While Python 3.6 is outside the range of versions covered in this book, it introduced some significant new features, and we include it here for historical context.

Version	New features	Breaking changes
3.8	• Assignment expressions (`:=`, aka the walrus operator) added • `/` and `*` in function argument lists to indicate positional-only and named-only arguments • Trailing = for debugging in f-strings (`f'{x=}'` short form for `f'x={x!r}'`) • Typing classes added (`Literal`, `TypedDict`, `Final`, `Protocol`) *Initial release: October 2019* *Planned end of support: October 2024*	• `time.clock()` removed; use `time.perf_counter()` • `pyvenv` script removed; use **`python -m venv`** • **`yield`** and **`yield from`** no longer allowed in comprehensions or genexps • `SyntaxWarning`s on **`is`** and **`is not`** tests against `str` and `int` literals added
3.9	• Union operators `|` and `|=` on `dict`s supported • `str.removeprefix()` and `str.removesuffix()` methods added • `zoneinfo` module added for IANA time zone support (to replace third-party `pytz` module) • Type hints can now use built-in types in generics (`list[int]` instead of `List[int]`) *Initial release: October 2020* *Planned end of support: October 2025*	• `array.array.tostring()` and `fromstring()` removed • `threading.Thread.isAlive()` removed (use `is_alive()` instead) • `ElementTree` and `Element`'s `getchildren()` and `getiterator()` removed • `base64.encodestring()` and `decodestring()` removed (use `encodebytes()` and `decodebytes()` instead) • `fractions.gcd()` removed (use `math.gcd()` instead) • `typing.NamedTuple._fields` removed (use `__annotations__` instead)

Version	New features	Breaking changes
3.10	• **`match`**/**`case`** structural pattern matching supported • Writing union types as `X	Y` (in type annotations and as second argument to `isinstance()`) allowed • Optional `strict` argument added to `zip()` built-in to detect sequences of differing lengths • Parenthesized context managers now officially supported; e.g., **`with`**`(`*`ctxmgr`*`, `*`ctxmgr`*`, ...):` *Initial release: October 2021* *Planned end of support: October 2026*	• Importing ABCs from `collections` removed (must now import from `collections.abc`) • `loop` parameter removed from most of `asyncio`'s high-level API
3.11	• Improved error messages • General performance boost • Exception groups and `except*` added • Typing classes added (`Never`, `Self`) • `tomllib` TOML parser added to stdlib *Initial release: October 2022* *Planned end of support: October 2027 (est.)*	• `binhex` module removed • `int` to `str` conversion restricted to 4,300 digits

Planning a Python Version Upgrade

Why upgrade in the first place? If you have a stable, running application, and a stable deployment environment, a reasonable decision might be to leave it alone. But version upgrades do come with benefits:

- New versions usually introduce new features, which may allow you to simplify code.
- Updated versions include bug fixes and refactorings, which can improve system stability and performance.

- Security vulnerabilities identified in an older version may be fixed in a new version.[2]

Eventually, old Python versions fall out of support, and projects running on older versions become difficult to staff and more costly to maintain. Upgrading might then become a necessity.

Choosing a Target Version

Before deciding which version to migrate to, sometimes you have to figure out first, "What version am I running now?" You may be unpleasantly surprised to find old software running unsupported Python versions lurking in your company's systems. Often this happens when those systems depend on some third-party package that is itself behind in version upgrades, or does not have an upgrade available. The situation is even more dire when such a system is critical in some way for company operations. You may be able to isolate the lagging package behind a remote-access API, allowing that package to run on the old version while permitting your own code to safely upgrade. The presence of systems with these upgrade constraints must be made visible to senior management, so they can be advised of the risks and trade-offs of retaining, upgrading, isolating, or replacing.

The choice of target version often defaults to "whatever version is the most current." This is a reasonable choice, as it is usually the most cost-effective option with respect to the investment involved in doing the upgrade: the most recent release will have the longest support period moving forward. A more conservative position might be "whatever version is the most current, minus 1." You can be reasonably sure that version *N*–1 has undergone some period of in-production testing at other companies, and someone else has shaken out most of the bugs.

Scoping the Work

After you have selected your target version of Python, identify all the breaking changes in the versions after the version your software is currently using, up to and including the target version (see the Appendix for a detailed table of features and breaking changes by version; additional details can be found in the "What's New in Python 3.*n*" sections of the online docs). Breaking changes are usually documented with a compatible form that will work with both your current version and the target version. Document and communicate the source changes that development teams will need to make before upgrading. (There may be significantly more work than expected involved in moving directly to the selected target version, if a lot of your code is affected by breaking changes or compatibility issues with related software. You may even end up revisiting the choice of target version or considering smaller

v3.7 to v3.n Migration

2 When this happens, it is usually an "all hands on deck" emergency situation to do the upgrade in a hurry. These events are the very ones you are trying to avoid, or at least minimize, by implementing a steady and ongoing Python version upgrade program.

steps. Perhaps you'll decide on upgrading to *target*–1 as a first step and deferring the task of the upgrade to *target* or *target*+1 for a subsequent upgrade project.)

Identify any third-party or open source libraries that your codebase uses, and ensure that they are compatible with (or have plans to be compatible with) the target Python version. Even if your own codebase is ready for upgrading to the target, an external library that lags behind may hold up your upgrade project. If necessary, you may be able to isolate such a library in a separate runtime environment (using virtual machines or container technologies), if that library offers a remote access programming interface.

Make the target Python version available in development environments, and optionally in deployment environments, so that developers can confirm that their upgrade changes are complete and correct.

Applying the Code Changes

Once you have decided on your target version and identified all the breaking changes, you'll need to make changes in your codebase to make it compatible with the target version. Your goal, ideally, is to have the code in a form that is compatible with both the current *and* target Python versions.

> **Imports from __future__**
>
> `__future__` is a standard library module containing a variety of features, documented in the online docs, to ease migration between versions. It is unlike any other module, because importing features can affect the syntax, not just the semantics, of your program. Such imports *must* be the initial executable statements of your code.
>
> Each "future feature" is activated using the statement:
>
> ```
> from __future__ import feature
> ```
>
> where *`feature`* is the name of the feature you want to use.
>
> In the span of versions this book covers, the only future feature you might consider using is:
>
> ```
> from __future__ import annotations
> ```
>
> which permits references to as-yet-undefined types without enclosing them in quotes (as covered in Chapter 5). If your current version is Python 3.7 or later, then adding this `__future__` import will permit use of the unquoted types in type annotations, so you don't have to redo them later.

Begin by reviewing libraries that are shared across multiple projects. Removing the blocking changes from these libraries will be a crucial first step, since you will be unable to deploy any dependent applications on the target version until this is done. Once a library is compatible with both versions, it can be deployed for use in the migration project. Moving forward, the library code must maintain compatibility with both the current Python version and the target version: shared libraries will likely be the *last* projects that will be able to utilize any new features of the target version.

Standalone applications will have earlier opportunities to use the new features in the target version. Once the application has removed all code affected by breaking changes, commit it to your source control system as a cross-version-compatible snapshot. Afterwards, you may add new features to the application code and deploy it into environments that support the target version.

If version compatibility changes affect type annotations, you can use *.pyi* stub files to isolate version-dependent typing from your source code.

Upgrade Automation Using pyupgrade

You may be able to automate much of the toil in upgrading your code using automation tools such as the `pyupgrade` package. `pyupgrade` analyzes the abstract syntax tree (AST) returned by Python's `ast.parse` function to locate issues and make corrections to your source code. You can select a specific target Python version using command-line switches.

Whenever you use automatic code conversion, review the output of the conversion process. A dynamic language like Python makes it impossible to perform a perfect translation; while testing helps, it can't pick up all imperfections.

Multiversion Testing

Make sure that your tests cover as much of your project as possible, so that inter-version errors are likely to be picked up during testing. Aim for at least 80% testing coverage; much more than 90% can be difficult to achieve, so don't spend too much effort trying to reach a too-ambitious standard. (*Mocks*, mentioned in "Unit Testing and System Testing" on page 514, can help you increase the breadth of your unit testing coverage, if not the depth.)

The tox package is useful to help you manage and test multiversion code. It lets you test your code under a number of different virtual environments, and it supports multiple CPython versions, as well as PyPy.

Use a Controlled Deployment Process

Make the target Python version available in deployment environments, with an application environment setting to indicate whether an application should run using the current or target Python version. Continuously track, and periodically report, the completion percentage to your management team.

How Often Should You Upgrade?

The PSF releases Python on a minor-release-per-year cadence, with each version enjoying five years of support after release. If you apply a latest-release-minus-1 strategy, it provides you with a stable, proven version to migrate to, with a four-year support horizon (in case a future upgrade needs to be deferred). Given the four-year time window, doing upgrades to the latest release minus 1 every year or two should provide a reasonable balance of periodic upgrade cost and platform stability.

Summary

Maintaining the version currency of the software that your organization's systems depend on is an ongoing habit of proper "software hygiene," in Python just like in any other development stack. By performing regular upgrades of just one or two versions at a time, you can keep this work at a steady and manageable level, and it will become a recognized and valued activity in your organization.

A
New Features and Changes in Python 3.7 Through 3.11

The following tables enumerate language and standard library changes in Python versions 3.7 through 3.11 that are most likely to be found in Python code. Use these tables to plan your upgrade strategy, as constrained by your exposure to breaking changes in your codebase.

The following types of changes are considered to be "breaking" and are marked with a **!** symbol in the last column:

- Introduces new keywords or built-ins (which may clash with names used in existing Python source code)
- Removes a method from a stdlib module or built-in type
- Changes a built-in or stdlib method signature in a way that is not backward-compatible (such as removing a parameter, or renaming a named parameter)

New warnings (including `DeprecatedWarning`) are also shown as "breaking," but marked with a * symbol in the last column.

Also see the table of proposed deprecations and removals from the standard library ("dead batteries") in PEP 594, which lists modules that are slated for deprecation or removal, the versions in which these changes are scheduled to be made (beginning with Python 3.12), and recommended replacements.

Python 3.7

The following table summarizes changes in Python version 3.7. For further details, see "What's New in Python 3.7" in the online docs.

Python 3.7	Added	Deprecated	Removed	Breaking change
Functions accept > 255 arguments	+			
`argparse.ArgumentParser.parse_intermixed_args()`	+			
`ast.literal_eval()` no longer evaluates addition and subtraction				!
`async` and **`await`** become reserved language keywords	+			!
`asyncio.all_tasks()`, `asyncio.create_task()`, `asyncio.current_task()`, `asyncio.get_running_loop()`, `asyncio.Future.get_loop()`, `asyncio.Handle.cancelled()`, `asyncio.loop.sock_recv_into()`, `asyncio.loop.sock_sendfile()`, `asyncio.loop.start_tls()`, `asyncio.ReadTransport.is_reading()`, `asyncio.Server.is_serving()`, `asyncio.Server.get_loop()`, `asyncio.Task.get_loop()`, `asyncio.run()` (provisional)	+			
`asyncio.Server` is an async context manager	+			
`asyncio.loop.call_soon()`, `asyncio.loop.call_soon_threadsafe()`, `asyncio.loop.call_later()`, `asyncio.loop.call_at()`, and `asyncio.Future.add_done_callback()` all accept optional named `context` argument	+			
`asyncio.loop.create_server()`, `asyncio.loop.create_unix_server()`, `asyncio.Server.start_serving()`, and `asyncio.Server.serve_forever()` all accept optional named `start_serving` argument	+			
`asyncio.Task.current_task()` and `asyncio.Task.all_tasks()` are deprecated; use `asyncio.current_task()` and `asyncio.all_tasks()`		—		*

Python 3.7	Added	Deprecated	Removed	Breaking change
`binascii.b2a_uu()` accepts named `backtick` argument	+			
`bool()` constructor no longer accepts a named argument (positional only)				!
`breakpoint()` built-in function	+			!
`bytearray.isascii()`	+			
`bytes.isascii()`	+			
`collections.namedtuple` supports default values	+			
`concurrent.Futures.ProcessPoolExecutor` and `concurrent.Futures.ThreadPoolExecutor` constructors accept optional `initializer` and `initargs` arguments	+			
`contextlib.AbstractAsyncContextManager`, `contextlib.asynccontextmanager()`, `contextlib.AsyncExitStack`, `contextlib.nullcontext()`	+			
`contextvars` module (similar to thread-local vars, with `asyncio` support)	+			
`dataclasses` module	+			
`datetime.datetime.fromisoformat()`	+			
`DeprecationWarning` shown by default in `__main__` module	+			*
`dict` maintaining insertion order now guaranteed; `dict.popitem()` returns items in LIFO order	+			
`__dir__()` at module level	+			
`dis.dis()` method accepts named `depth` argument	+			
`float()` constructor no longer accepts a named argument (positional only)				!
`fpectl` module removed			X	!
`from` `__future__` **`import`** `annotations` enables referencing as-yet-undefined types in type annotations without enclosing in quotes	+			
`gc.freeze()`	+			
`__getattr__()` at module level	+			
`hmac.digest()`	+			
`http.client.HTTPConnection` and `http.client.HTTPSConnection` constructors accept optional `blocksize` argument	+			

Python 3.7	Added	Deprecated	Removed	Breaking change
`http.server.ThreadingHTTPServer`	+			
`importlib.abc.ResourceReader`, `importlib.resources` module, `importlib.source_hash()`	+			
`int()` constructor no longer accepts a named *x* argument (positional only; named `base` argument is still supported)				!
`io.TextIOWrapper.reconfigure()`	+			
`ipaddress.IPv*Network.subnet_of()`, `ipaddress.IPv*Network.supernet_of()`	+			
`list()` constructor no longer accepts a named argument (positional only)				!
`logging.StreamHandler.setStream()`	+			
`math.remainder()`	+			
`multiprocessing.Process.close()`, `multiprocessing.Process.kill()`	+			
`ntpath.splitunc()` removed; use `ntpath.splitdrive()`			X	!
`os.preadv()`, `os.pwritev()`, `os.register_at_fork()`	+			
`os.stat_float_times()` removed (compatibility function with Python 2; all timestamps in `stat` result are `float`s in Python 3)			X	!
`pathlib.Path.is_mount()`	+			
`pdb.set_trace()` accepts named `header` argument	+			
`plist.Dict`, `plist.Plist`, and `plist._InternalDict` removed			X	!
`queue.SimpleQueue`	+			
`re` compiled expressions and match objects can be copied with `copy.copy` and `copy.deepcopy`	+			
`re.sub()` no longer supports unknown escapes of `\` and an ASCII letter			X	!
`socket.close()`, `socket.getblocking()`, `socket.TCP_CONGESTION`, `socket.TCP_USER_TIMEOUT`, `socket.TCP_NOTSENT_LOWAT` (Linux platforms only)	+			
`sqlite3.Connection.backup()`	+			
`StopIteration` handling in generators	+			

Python 3.7	Added	Deprecated	Removed	Breaking change
`str.isascii()`	+			
`subprocess.run()` named argument `capture_output=True` for simplified `stdin`/`stdout` capture	+			
`subprocess.run()` and `subprocess.Popen()` named argument `text`, alias for `universal_newlines`	+			
`subprocess.run()`, `subprocess.call()`, and `subprocess.Popen()` improved `KeyboardInterrupt` handling	+			
`sys.breakpointhook()`, `sys.getandroidapilevel()`, `sys.get_coroutine_origin_tracking_depth()`, `sys.set_coroutine_origin_tracking_depth()`	+			
`time.clock_gettime_ns()`, `time.clock_settime_ns()`, `time.monotonic_ns()`, `time.perf_counter_ns()`, `time.process_time_ns()`, `time.time_ns()`, `time.CLOCK_BOOTTIME`, `time.CLOCK_PROF`, `time.CLOCK_UPTIME`	+			
`time.thread_time()` and `time.thread_time_ns()` for per-thread CPU timing	+			
`tkinter.ttk.Spinbox`	+			
`tuple()` constructor no longer accepts a named argument (positional only)				!
`types.ClassMethodDescriptorType`, `types.MethodDescriptorType`, `types.MethodWrapperType`, `types.WrapperDescriptorType`	+			
`types.resolve_bases()`	+			
`uuid.UUID.is_safe`	+			
`yield` and **`yield from`** in comprehensions or generator expressions are deprecated		—		*
`zipfile.ZipFile` constructor accepts named `compresslevel` argument	+			

Python 3.8

The following table summarizes changes in Python version 3.8. For further details, see "What's New in Python 3.8" in the online docs.

Python 3.8	Added	Deprecated	Removed	Breaking change
Assignment expressions (`:=` "walrus" operator)	+			
Positional-only and named-only parameters (`/` and `*` arg separators)	+			
F-string trailing = for debugging	+			
`is` and **`is not`** tests against `str` and `int` literals emit `SyntaxWarning`				*
`ast` AST nodes `end_lineno` and `end_col_offset` attributes	+			
`ast.get_source_segment()`	+			
`ast.parse()` accepts named arguments `type_comments`, `mode`, and `feature_version`	+			
`async` REPL can be run using **`python -m asyncio`**	+			
`asyncio` tasks can be named	+			
`asyncio.coroutine` decorator deprecated		—		*
`asyncio.run()` to execute a coroutine directly	+			
`asyncio.Task.get_coro()`	+			
`bool.as_integer_ratio()`	+			
`collections.namedtuple._asdict()` returns `dict` instead of `OrderedDict`	+			
`continue` permitted in **`finally`** block	+			
`cgi.parse_qs`, `cgi.parse_qsl`, and `cgi.escape` removed; import from `urllib.parse` and `html` modules			X	!
`csv.DictReader` returns `dicts` instead of `OrderedDicts`	+			
`datetime.date.fromisocalendar()`, `datetime.datetime.fromisocalendar()`	+			
`dict` comprehensions compute key first, value second				!
`dict` and `dictviews` returned from `dict.keys()`, `dict.values()` and `dict.items()` now iterable with `reversed()`	+			
`fractions.Fraction.as_integer_ratio()`	+			

Python 3.8	Added	Deprecated	Removed	Breaking change
`functools.cached_property()` decorator (see cautionary notes here and here)	+			
`functools.lru_cache` can be used as a decorator without `()`	+			
`functools.singledispatchmethod` decorator	+			
`gettext.pgettext()`	+			
`importlib.metadata` module	+			
`int.as_integer_ratio()`	+			
`itertools.accumulate()` accepts named `initial` argument	+			
`macpath` module removed			X	!
`math.comb()`, `math.dist()`, `math.isqrt()`, `math.perm()`, `math.prod()`	+			
`math.hypot()` added support for > 2 dimensions	+			
`multiprocessing.shared_memory` module	+			
`namedtuple._asdict()` returns `dict` instead of `OrderedDict`	+			
`os.add_dll_directory()` on Windows	+			
`os.memfd_create()`	+			
`pathlib.Path.link_to()`	+			
`platform.popen()` removed; use `os.popen()`			X	!
`pprint.pp()`	+			
pyvenv script removed; use **`python -m venv`**			X	!
`re` regular expression patterns support `\N{`*`name`*`}` escapes	+			
`shlex.join()` (inverse of `shlex.split()`)	+			
`shutil.copytree()` accepts named `dirs_exist_ok` argument	+			
`__slots__` accepts a `dict` of `{`*`name`*`: `*`docstring`*`}`	+			
`socket.create_server()`, `socket.has_dualstack_ipv6()`	+			
`socket.if_nameindex()`, `socket.if_nametoindex()`, and `socket.if_indextoname()` are all supported on Windows	+			
`sqlite3` `Cache` and `Statement` objects no longer user-visible			X	!

Python 3.8	Added	Deprecated	Removed	Breaking change
ssl.post_handshake_auth(), ssl.verify_client_post_handshake()	+			
statistics.fmean(), statistics.geometric_mean(), statistics.multimode(), statistics.NormalDist, statistics.quantiles()	+			
sys.get_coroutine_wrapper() and sys.set_coroutine_wrapper() removed			X	!
sys.unraisablehook()	+			
tarfile.filemode() removed			X	!
threading.excepthook(), threading.get_native_id(), threading.Thread.native_id	+			
time.clock() removed; use time.perf_counter()			X	!
tkinter.Canvas.moveto(), tkinter.PhotoImage.transparency_get(), tkinter.PhotoImage.transparency_set(), tkinter.Spinbox.selection_from(), tkinter.Spinbox.selection_present(), tkinter.Spinbox.selection_range(), tkinter.Spinbox.selection_to()	+			
typing.Final, typing.get_args(), typing.get_origin(), typing.Literal, typing.Protocol, typing.SupportsIndex, typing.TypedDict	+			
typing.NamedTuple._field_types deprecated		—		*
unicodedata.is_normalized()	+			
unittest supports coroutines as test cases	+			
unittest.addClassCleanup(), unittest.addModuleCleanup(), unittest.AsyncMock	+			
xml.etree.Element.getchildren(), xml.etree.Element.getiterator(), xml.etree.ElementTree.getchildren(), and xml.etree.ElementTree.getiterator() deprecated		—		*
XMLParser.doctype() removed			X	!
xmlrpc.client.ServerProxy accepts named headers argument	+			

Python 3.8	Added	Deprecated	Removed	Breaking change
yield and **return** unpacking no longer requires enclosing parentheses	+			
yield and **yield from** no longer allowed in comprehensions or generator expressions			X	!

Python 3.9

The following table summarizes changes in Python version 3.9. For further details, see "What's New in Python 3.9" in the online docs.

Python 3.9	Added	Deprecated	Removed	Breaking change
Type annotations can now use built-in types in generics (e.g., list[int] instead of List[int])	+			
array.array.tostring() and array.array.fromstring() removed; use tobytes() and frombytes()			X	!
ast.unparse()	+			
asyncio.loop.create_datagram_endpoint() argument reuse_address disabled				!
asyncio.PidfdChild Watcher, asyncio.shutdown_default_executor(), asyncio.to_thread()	+			
asyncio.Task.all_asks removed; use asyncio.all_tasks()			X	!
asyncio.Task.current_task removed; use asyncio.current_task()			X	!
base64.encodestring() and base64.decode string() removed; use base64.encodebytes() and base64.decodebytes()			X	!
concurrent.futures.Executor.shutdown() accepts named cancel_futures argument	+			
curses.get_escdelay(), curses.get_tabsize(), curses.set_escdelay(), curses.set_tabsize()	+			
dict supports union operators | and |=	+			
fcntl.F_OFD_GETLK, fcntl.F_OFD_SETLK, fcntl.F_OFD_SETKLW	+			

Python 3.9	Added	Deprecated	Removed	Breaking change
`fractions.gcd()` removed; use `math.gcd()`			X	!
`functools.cache()` (lightweight/faster version of `lru_cache`)	+			
`gc.is_finalized()`	+			
`graphlib` module with `TopologicalSorter` class	+			
`html.parser.HTMLParser.unescape()` removed			X	!
`imaplib.IMAP4.unselect()`	+			
`importlib.resources.files()`	+			
`inspect.BoundArguments.arguments` returns `dict` instead of `OrderedDict`	+			
`ipaddress` module does not accept leading zeros in IPv4 address strings				!
`logging.getLogger('root')` returns the root logger	+			!
`math.gcd()` accepts multiple arguments	+			
`math.lcm()`, `math.nextafter()`, `math.ulp()`	+			
`multiprocessing.SimpleQueue.close()`	+			
`nntplib.NNTP.xpath()` and `nntplib.xgtitle()` removed			X	!
`os.pidfd_open()`	+			
`os.unsetenv()` available on Windows	+			
`os.waitstatus_to_exitcode()`	+			
`parser` module deprecated		—		*
`pathlib.Path.readlink()`	+			
`plistlib` API removed			X	!
`pprint` supports `types.SimpleNamespace`	+			
`random.choices()` with `weights` argument raises `ValueError` if `weights` are all `0`				!
`random.Random.randbytes()`	+			
`socket.CAN_RAW_JOIN_FILTERS`, `socket.send_fds()`, `socket.recv_fds()`	+			
`str.removeprefix()`, `str.removesuffix()`	+			
`symbol` module deprecated		—		*

Python 3.9	Added	Deprecated	Removed	Breaking change
sys.callstats(), sys.getcheckinterval(), sys.getcounts(), and sys.setcheckinterval() removed			X	!
sys.getcheckinterval() and sys.setcheckinterval() removed; use sys.getswitchinterval() and sys.setswitchinterval()			X	!
sys.platlibdir attribute	+			
threading.Thread.isAlive() removed; use threading.Thread.is_alive()			X	!
tracemalloc.reset_peak()	+			
typing.Annotated type	+			
typing.Literal deduplicates values; equality matching is order independent (3.9.1)				!
typing.NamedTuple._field_types removed; use __annotations__			X	!
urllib.parse.parse_qs() and urllib.parse.parse_qsl() accept ; or & query parameter separator, but not both (3.9.2)				!
urllib.parse.urlparse() changed handling of numeric paths; a string like 'path:80' is no longer parsed as a path but as a scheme ('path') and a path ('80')				!
with (**await** asyncio.Condition) and **with** (**yield from** asyncio.Condition) removed; use **async with** condition			X	!
with (**await** asyncio.lock) and **with** (**yield from** asyncio.lock) removed; use **async with** lock			X	!
with (**await** asyncio.Semaphore) and **with** (**yield from** asyncio.Semaphore) removed; use **async with** semaphore			X	!
xml.etree.Element.getchildren(), xml.etree.Element.getiterator(), xml.etree.ElementTree.getchildren(), and xml.etree.ElementTree.getiterator() removed			X	!
zoneinfo module for IANA time zone support	+			

Python 3.10

The following table summarizes changes in Python version 3.10. For further details, see "What's New in Python 3.10" in the online docs.

Python 3.10	Added	Deprecated	Removed	Breaking change
Building requires OpenSSL 1.1.1 or newer	+			
Debugging improved with precise line numbers	+			
Structural pattern matching using **`match`**, **`case`**, and _ soft keywords[a]	+			
`aiter()` and `anext()` built-ins	+			!
`array.array.index()` accepts optional arguments `start` and `stop`	+			
`ast.literal_eval(`*`s`*`)` strips leading spaces and tabs from input string *s*	+			
`asynchat` module deprecated		—		*
`asyncio` functions remove `loop` parameter			X	!
`asyncio.connect_accepted_socket()`	+			
`asyncore` module deprecated		—		*
`base64.b32hexdecode`, `base64.b32hexencode`	+			
`bdb.clearBreakpoints()`	+			
`bisect.bisect`, `bisect.bisect_left`, `bisect.bisect_right`, `bisect.insort`, `bisect.insort_left`, and `bisect.insert_right` all accept optional `key` argument	+			
`cgi.log` deprecated		—		*
`codecs.unregister()`	+			
`collections` module compatibility definitions of ABCs removed; use `collections.abc`			X	!
`collections.Counter.total()`	+			
`contextlib.aclosing()` decorator, `contextlib.AsyncContextDecorator`	+			
`curses.has_extended_color_support()`	+			
`dataclasses.dataclass()` decorator accepts optional `slots` argument	+			
`dataclasses.KW_ONLY`	+			

Python 3.10	Added	Deprecated	Removed	Breaking change
`distutils` deprecated, to be removed in Python 3.12		—		*
`enum.StrEnum`	+			
`fileinput.input()` and `fileinput.FileInput` accept optional `encoding` and `errors` arguments	+			
`formatter` module removed			X	!
`glob.glob()` and `glob.iglob()` accept optional `root_dir` and `dir_fd` arguments to specify root search directory	+			
`importlib.metadata.package_distributions()`	+			
`inspect.get_annotations()`	+			
`int.bit_count()`	+			
`isinstance(obj, (atype, btype))` can be written `isinstance(obj, atype|btype)`	+			
`issubclass(cls, (atype, btype))` can be written `issubclass(cls, atype|btype)`	+			
`itertools.pairwise()`	+			
`os.eventfd()`, `os.splice()`	+			
`os.path.realpath()` accepts optional `strict` argument	+			
`os.EVTONLY`, `os.O_FSYNC`, `os.O_SYMLINK`, and `os.O_NOFOLLOW_ANY` all added on macOS	+			
`parser` module removed			X	!
`pathlib.Path.chmod()` and `pathlib.Path.stat()` accept optional `follow_symlinks` keyword argument	+			
`pathlib.Path.hardlink_to()`	+			
`pathlib.Path.link_to()` deprecated; use `hardlink_to()`		—		*
`platform.freedesktop_os_release()`	+			
`pprint.pprint()` accepts optional `underscore_numbers` keyword argument	+			
`smtpd` module deprecated		—		*
`ssl.get_server_certificate` accepts optional `timeout` argument	+			

<table>
<thead>
<tr><th>Python 3.10</th><th>Added</th><th>Deprecated</th><th>Removed</th><th>Breaking change</th></tr>
</thead>
<tbody>
<tr><td>statistics.correlation(), statistics.covariance(), statistics.linear_regression()</td><td>+</td><td></td><td></td><td></td></tr>
<tr><td>SyntaxError.end_line_no and SyntaxError.end_offset attributes</td><td>+</td><td></td><td></td><td></td></tr>
<tr><td>sys.flags.warn_default_encoding to emit EncodingWarning</td><td>+</td><td></td><td></td><td>*</td></tr>
<tr><td>sys.orig_argv and sys.stdlib_module_names attributes</td><td>+</td><td></td><td></td><td></td></tr>
<tr><td>threading.__excepthook__</td><td>+</td><td></td><td></td><td></td></tr>
<tr><td>threading.getprofile(), threading.gettrace()</td><td>+</td><td></td><td></td><td></td></tr>
<tr><td>threading.Thread appends '(<target.__name__>)' to generated thread names</td><td>+</td><td></td><td></td><td></td></tr>
<tr><td>traceback.format_exception(), traceback.format_exception_only(), and traceback.print_exception() signature changes</td><td></td><td></td><td></td><td>!</td></tr>
<tr><td>types.EllipsisType, types.NoneType, types.NotImplementedType</td><td>+</td><td></td><td></td><td></td></tr>
<tr><td>typing module includes parameter specification variables for specifying Callable types</td><td>+</td><td></td><td></td><td></td></tr>
<tr><td>typing.io module deprecated; use typing</td><td></td><td>—</td><td></td><td>*</td></tr>
<tr><td>typing.is_typeddict()</td><td>+</td><td></td><td></td><td></td></tr>
<tr><td>typing.Literal deduplicates values; equality matching is order-independent</td><td></td><td></td><td></td><td>!</td></tr>
<tr><td>typing.Optional[X] can be written as X | None</td><td>+</td><td></td><td></td><td></td></tr>
<tr><td>typing.re module deprecated; use typing</td><td></td><td>—</td><td></td><td>*</td></tr>
<tr><td>typing.TypeAlias for defining explicit type aliases</td><td>+</td><td></td><td></td><td></td></tr>
<tr><td>typing.TypeGuard</td><td>+</td><td></td><td></td><td></td></tr>
<tr><td>typing.Union[X, Y] can use | operator as X | Y</td><td>+</td><td></td><td></td><td></td></tr>
<tr><td>unittest.assertNoLogs()</td><td>+</td><td></td><td></td><td></td></tr>
<tr><td>urllib.parse.parse_qs() and urllib.parse.parse_qsl() accept ; or & query parameter separator, but not both</td><td></td><td></td><td></td><td>!</td></tr>
<tr><td>with statement accepts parenthesized context managers: with(ctxmgr, ctxmgr, ...)</td><td>+</td><td></td><td></td><td></td></tr>
<tr><td>xml.sax.handler.LexicalHandler</td><td>+</td><td></td><td></td><td></td></tr>
</tbody>
</table>

Python 3.10	Added	Deprecated	Removed	Breaking change
`zip` built-in accepts optional `strict` named argument for length-checking	+			
`zipimport.find_spec()`, `zipimport.zipimporter.create_module()`, `zipimport.zipimporter.exec_module()`, `zipimport.zipimporter.invalidate_caches()`	+			

[a] Since these are defined as *soft* keywords, they do not break existing code using those same names.

Python 3.11

The following table summarizes changes in Python version 3.11. For further details, see "What's New in Python 3.11" in the online docs.

Python 3.11	Added	Deprecated	Removed	Breaking change
Security patch released in Python 3.11.0 and backported to versions 3.7–3.10: `int` conversion to `str` and `str` conversion to `int` in bases other than 2, 4, 8, 16, or 32 raises `ValueError` if the resulting string > 4,300 digits (addresses CVE-2020-10735)				!
General performance improvements	+			
Improved error messages	+			
New syntax: **`for`** *`x`* **`in`** `*`*`values`*	+			
`aifc` module deprecated		—		*
`asynchat` and `asyncore` modules deprecated		—		*
`asyncio.Barrier`, `asyncio.start_tls()`, `asyncio.TaskGroup`	+			
`asyncio.coroutine` decorator removed			X	!
`asyncio.loop.create_datagram_endpoint()` argument `reuse_address` removed			X	!
`asyncio.TimeoutError` deprecated; use `TimeoutError`		—		*
`audioop` module deprecated		—		*
`BaseException.add_note()`, `BaseException.__notes__` attribute	+			

Python 3.11	Added	Deprecated	Removed	Breaking change
binascii.a2b_hqx(), binascii.b2a_hqx(), binascii.rlecode_hqx(), and binascii.rledecode_hqx() removed			X	!
binhex module removed			X	!
cgi and cgitb modules deprecated		—		*
chunk module deprecated		—		*
concurrent.futures.ProcessPoolExecutor() max_tasks_per_child argument	+			
concurrent.futures.TimeoutError deprecated; use built-in TimeoutError		—		*
contextlib.chdir context manager (change current working dir and then restore it)	+			
crypt module deprecated		—		*
dataclasses check for mutable defaults disallows any value that is not hashable (formerly allowed any value that was not a dict, list, or set)				!
datetime.UTC as a convenience alias for datetime.timezone.utc	+			
enum.Enum str() output just gives name	+			
enum.EnumCheck, enum.FlagBoundary, enum.global_enum() decorator, enum.member() decorator, enum.nonmember() decorator, enum.property, enum.ReprEnum, enum.StrEnum, and enum.verify()	+			
ExceptionGroups and except*	+			
fractions.Fraction initialization from string	+			
gettext.l*gettext() methods removed			X	!
glob.glob() and glob.iglob() accept optional include_hidden argument	+			
hashlib.file_digest()	+			
imghdr module deprecated		—		*
inspect.formatargspec() and inspect.getargspec() removed; use inspect.signature()			X	!
inspect.getmembers_static(), inspect.ismethodwrapper()	+			

Python 3.11	Added	Deprecated	Removed	Breaking change
locale.getdefaultlocale() and locale.resetlocale() deprecated		—		*
locale.getencoding()	+			
logging.getLevelNamesMapping()	+			
mailcap module deprecated		—		*
math.cbrt() (cube root), math.exp2() (computes 2^n)	+			
msilib module deprecated		—		*
nis module deprecated		—		*
nntplib module deprecated		—		*
operator.call	+			
ossaudiodev module deprecated		—		*
pipes module deprecated		—		*
re pattern syntax supports *+, ++, ?+, and {m,n}+ possessive quantifiers, and (?>...) atomic grouping	+			
re.template() deprecated		—		*
smtpd module deprecated		—		*
sndhdr module deprecated		—		*
spwd module deprecated		—		*
sqlite3.Connection.blobopen(), sqlite3.Connection.create_window_function(), sqlite3.Connection.deserialize(), sqlite3.Connection.getlimit(), sqlite3.Connection.serialize(), sqlite3.Connection.setlimit()	+			
sre_compile, sre_constants, and sre_parse deprecated		—		*
statistics.fmean() optional weights argument	+			
sunau module deprecated		—		*
sys.exception() (equivalent to sys.exc_info()[1])	+			
telnetlib module deprecated		—		*
time.nanosleep() (Unix-like systems only)	+			
tomllib TOML parser module	+			

Python 3.11	Added	Deprecated	Removed	Breaking change
`typing.assert_never()`, `typing.assert_type()`, `typing.LiteralString`, `typing.Never`, `typing.reveal_type()`, `typing.Self`	+			
`typing.Text` deprecated; use `str`		—		*
`typing.TypedDict` items can be marked as `Required` or `NotRequired`	+			
`typing.TypedDict(a=int, b=str)` form deprecated		—		*
`unicodedata` updated to Unicode 14.0.0	+			
`unittest.enterModuleContext()`, `unittest.IsolatedAsyncioTestCase.enterAsyncContext()`, `unittest.TestCase.enterClassContext()`, `unittest.TestCase.enterContext()`	+			
`unittest.findTestCases()`, `unittest.getTestCaseName()`, and `unittest.makeSuite()` deprecated; use methods of `unittest.TestLoader`		—		*
`uu` module deprecated		—		*
`with` statement now raises `TypeError` instead of `AttributeError` for objects that do not support the context manager protocol				!
`xdrlib` module deprecated		—		*
`z` string format specifier added, for negative sign of values close to zero	+			
`zipfile.ZipFile.mkdir()` added	+			
Add your own notes here:				

Index

Symbols

A

B

C

D

E

F

G

H

I

J

M

N

O

P

Q

R

S

T

U

V

W

X

Y

Z

About the Authors

Alex Martelli has been programming for 40 years, mainly in Python for the recent half of that time. He wrote the first two editions of Python in a Nutshell, and coauthored the first two editions of the *Python Cookbook* and the third edition of *Python in a Nutshell*. He is a PSF Fellow and Core Committer (emeritus), and won the 2002 Activators' Choice Award and the 2006 Frank Willison Memorial Award for contributions to the Python community. He is active on Stack Overflow and a frequent speaker at technical conferences. He's been living in Silicon Valley with his wife Anna for 17 years, and working at Google throughout this time, currently as Senior Staff Engineer in Google Cloud Tech Support.

Anna Martelli Ravenscroft is a PSF Fellow and winner of the 2013 Frank Willison Memorial Award for contributions to the Python community. She coauthored the second edition of the *Python Cookbook* and third edition of *Python in a Nutshell*. She has been a technical reviewer for many Python books and is a regular speaker and track chair at technical conferences. Anna lives in Silicon Valley with her husband Alex, two dogs, one cat, and several chickens.

Passionate about programming and community, **Steve Holden** has worked with computers since 1967 and started using Python at version 1.4 in 1995. He has since written about Python, created instructor-led training, delivered it to an international audience, and built 40 hours of video training for "reluctant Python users." An Emeritus Fellow of the Python Software Foundation, Steve served as a director of the Foundation for eight years and as its chairman for three; he created PyCon, the Python community's international conference series, and was presented with the 2007 Frank Willison Memorial Award for services to the Python community. He lives in Hastings, England, and works as Technical Architect for the UK Department for International Trade, where he is responsible for the systems that maintain and regulate the trading environment.

Paul McGuire has been programming for 40+ years, in languages ranging from FORTRAN to Pascal, PL/I, COBOL, Smalltalk, Java, C/C++/C#, and Tcl, settling on Python as his language of choice in 2001. He is a PSF Fellow, and is the author and maintainer of the popular pyparsing module, as well as littletable and plusminus. Paul authored the O'Reilly book *Getting Started with Pyparsing*, and has written and edited articles for *Python Magazine*. He has also spoken at PyCon, PyTexas, and at the Austin Python User's Group, and is active on StackOverflow. Paul now lives in Austin, Texas, with his wife and dog, and works for Indeed as a Site Reliability Engineer, helping people get jobs!

Colophon

The animal on the cover of *Python in a Nutshell*, fourth edition, is an African rock python (*Python sebae*), one of the six largest snake species in the world. They are native to sub-Saharan Africa, but can also be found in other parts of the world. They can live in a wide range of habitats from temperate forests and grasslands to tropical savanna and forests. While they live mainly on the ground, they are also excellent swimmers and climbers and like to live near areas with a permanent water source. Additionally, they can be found near human settlements due to the presence of rats, mice, and other vermin.

The average size of this species of python is between ten and thirteen feet. They have large, stout bodies covered in colored blotches and irregular stripes, varying in color between brown, olive, chestnut, and yellow, fading to white on their underside. African rock pythons have triangular heads with a brown spearhead shape on top, outlined in yellow.

Pythons are nonvenomous constrictor snakes that kill their prey by suffocation. While the snake's sharp teeth grip and hold the prey in place, the python's long body coils around its victim's chest, constricting tighter each time it exhales. African rock pythons feed on a wide range of mammals and birds, such as rodents, lizards, vultures, fowl, dogs, and goats. Python attacks on humans are extremely rare and only occur when provoked.

African rock pythons are not endangered, but there are threats to their species due to habitat loss, hunting, and the pet trade. Many of the animals on O'Reilly covers are endangered; all of them are important to the world.

The cover image is by Karen Montgomery, based on a black and white 19th-century engraving from the Dover Pictorial Archive. The cover fonts are Gilroy Semibold and Guardian Sans. The text font is Adobe Minion Pro; the heading font is Adobe Myriad Condensed; and the code font is Dalton Maag's Ubuntu Mono.