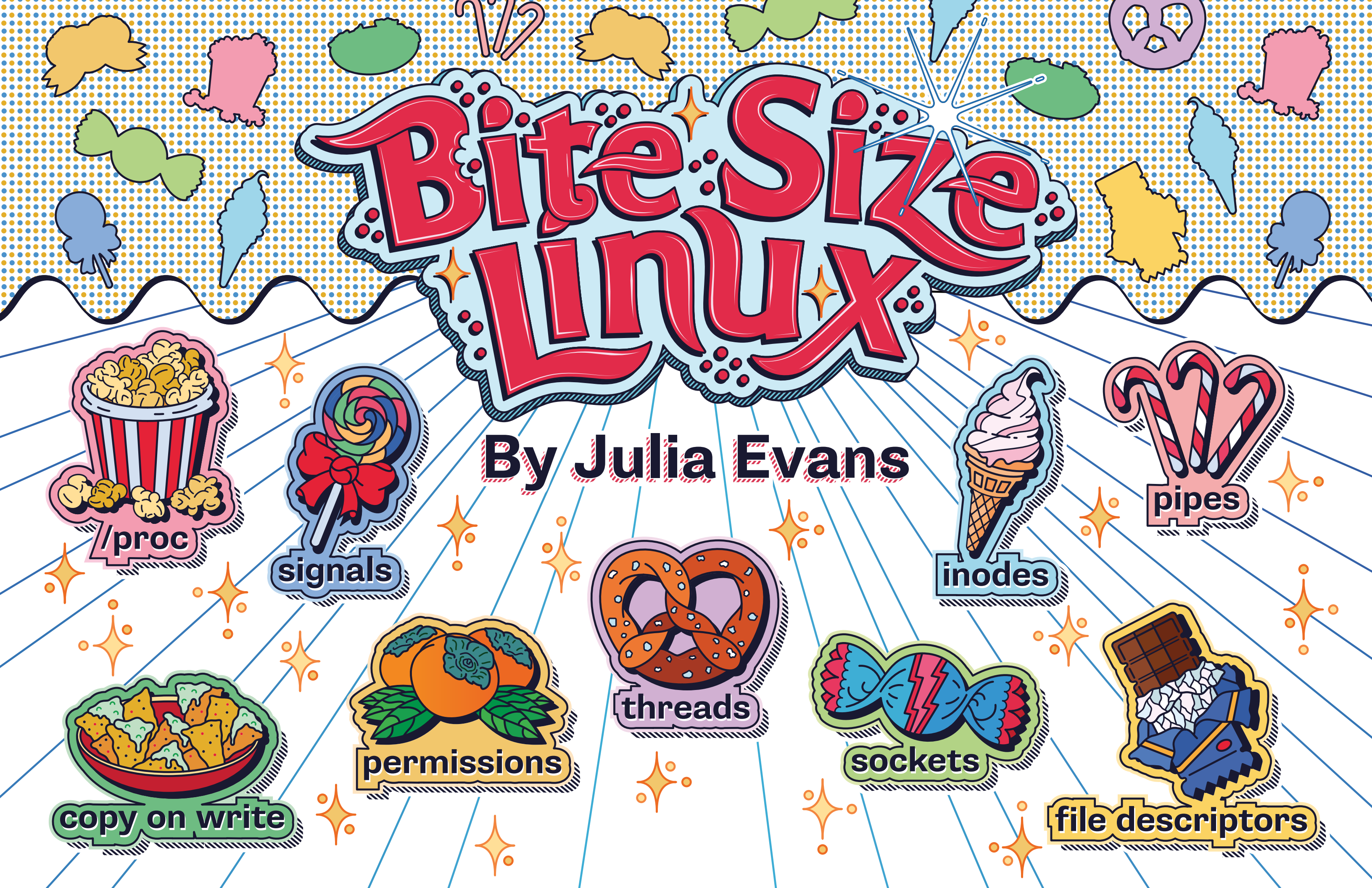
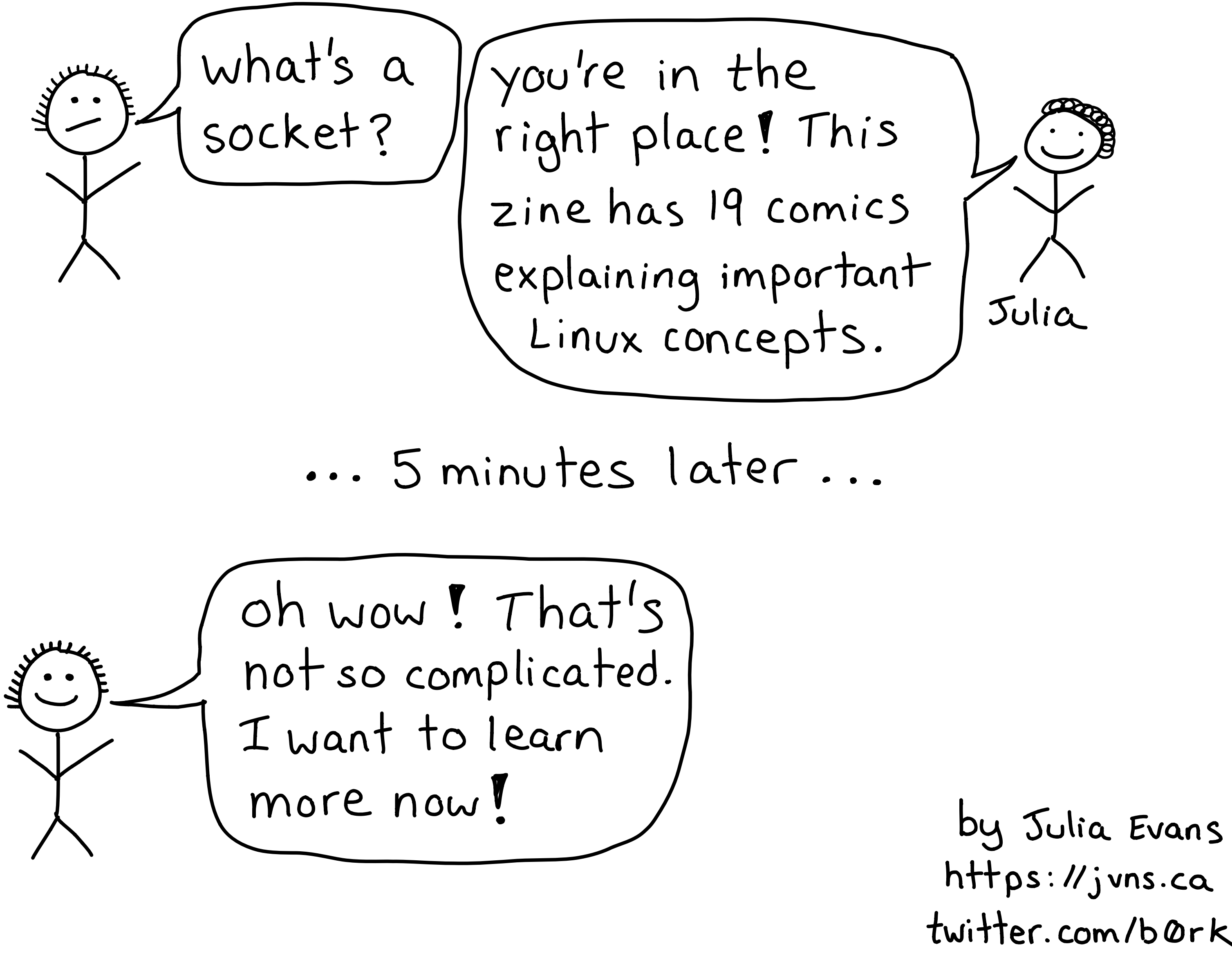
Bite Size Linux

By Julia Evans




what's a socket?
you're in the right place! This zine has 19 comics explaining important Linux concepts.
Julia
... 5 minutes later ...
oh wow! That's not so complicated. I want to learn more now!
by Julia Evans
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♥ Table of contents ♥

unix permissions

There are 3 things you can do to a file

read **w**rite e**x**ecute

ls -l file.txt shows you permissions. Here's how to interpret the output:

rw- rw- r-- bork staff

bork (user) can read & write

staff (group) can read & write

ANYONE can read

File permissions are 12 bits

setuid setgid sticky	user	group	all
000	110	110	100
	r w x	r w x	r w x

For files:

- r = can read
- w = can write
- x = can execute

For directories, it's approximately:

- r = can list files
- w = can create files
- x = can cd into & access files

110 in binary is 6

So	rw-	r--	r--
=	110	100	100
=	6	4	4

chmod 644 file.txt

means change the permissions to:

rw- r-- r--

Simple!

setuid affects executables

$ls -l /bin/ping

rws r-x r-x root root

this means ping always runs as root

setgid does 3 different unrelated things for executables, directories, and regular files.

an amazing directory: /proc

Every process on Linux has a PID (process ID) like 42.

In /proc/42, there's a lot of VERY USEFUL information about process 42.

/proc/PID/cmdline

command line arguments the process was started with

/proc/PID/exe

symlink to the process's binary. magic: works even if the binary has been deleted!

/proc/PID/environ

all of the process's environment variables

/proc/PID/status

Is the program running or asleep? How much memory is it using? And much more!

/proc/PID/fd

Directory with every file the process has open!

Run `$ ls -l /proc/42/fd` to see the list of files for process 42.

These symlinks are also magic & you can use them to recover deleted files ♥

/proc/PID/stack

The kernel's current stack for the process. Useful if it's stuck in a system call.

/proc/PID/maps

List of process's memory maps. Shared libraries, heap, anonymous maps, etc.

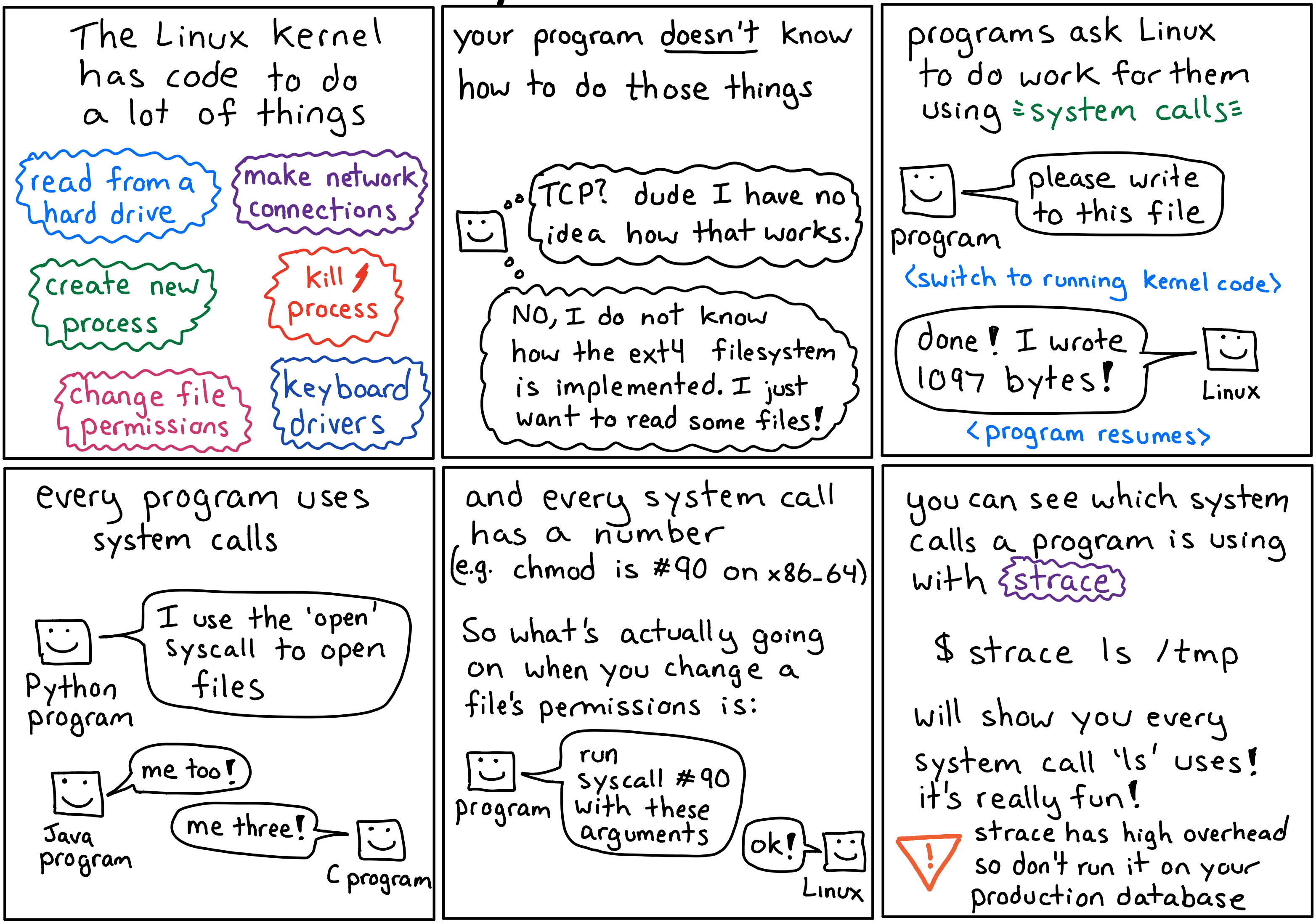
and more

Look at

man proc

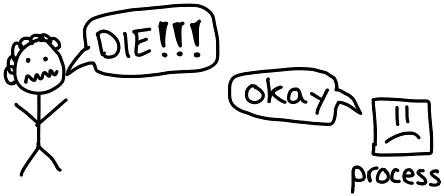
for more information!

system calls



signals

If you've ever used kill you've used signals



the Linux kernel sends processes signals in lots of situations

- your child terminated
- that pipe is closed
- illegal instruction
- the timer you set expired
- segmentation fault

you can send signals yourself with the kill system call or command

SIGINT	ctrl-C	various levels of "die"
SIGTERM	kill	
SIGKILL	kill -9	

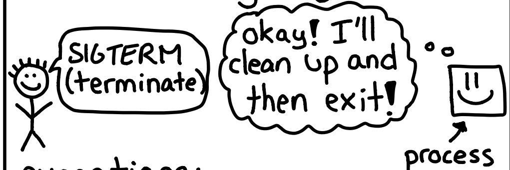
SIGHUP kill -HUP

often interpreted as "reload config", e.g. by nginx

Every signal has a default action, which is one of:

- ignore
- kill process
- kill process AND make core dump file
- stop process
- resume process

Your program can set custom handlers for almost any signal

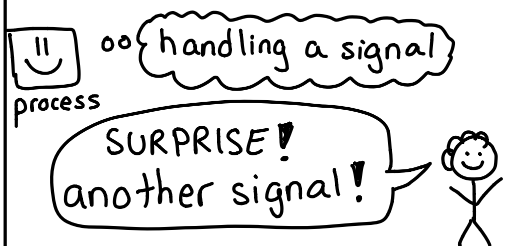


exceptions:

SIGSTOP & SIGKILL can't be ignored

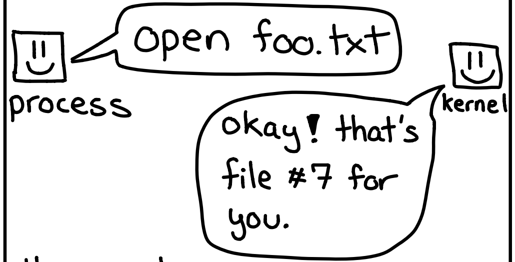
got SIGKILLed

signals can be hard to handle correctly since they can happen at ANY time



file descriptors

Unix systems use integers to track open files



these integers are called **file descriptors**

---

lsof (**list open files**) will show you a process's open files

$ lsof -p 4242 ← PID we're interested in

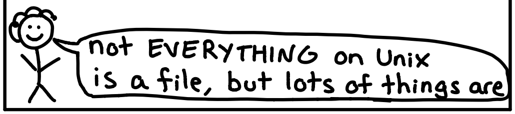
FD	NAME
0	/dev/pts/tty1
1	/dev/pts/tty1
2	pipe: 29174
3	/home/bork/awesome.txt
5	/tmp/

↑ FD is for file descriptor

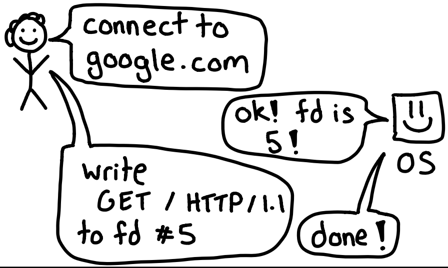
---

file descriptors can refer to:

- → files on disk
- → pipes
- → sockets (network connections)
- → terminals (like xterm)
- → devices (your speaker! /dev/null!)
- → LOTS MORE (eventfd, inotify, signalfd, epoll, etc.)



When you read or write to a file/pipe/network connection you do that using a file descriptor

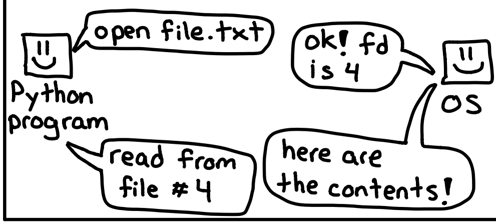


Let's see how some simple Python code works under the hood:

Python:

```
f = open("file.txt")
f.readlines()
```

Behind the scenes:



(almost) every process has 3 standard FDs:

stdin → 0
stdout → 1
stderr → 2

"read from stdin"
means
"read from the file descriptor 0"

↗ could be a pipe or file or terminal

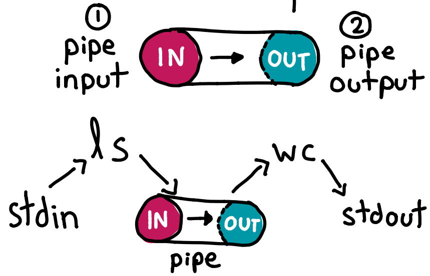
pipes

Sometimes you want to send the output of one process to the input of another

```
$ ls | wc -l
53
```

53 files!

a pipe is a pair of 2 magical file descriptors



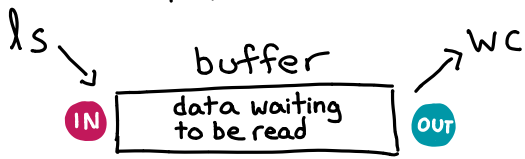
when ls does write(IN, "hi"), wc can read it!

read(OUT)

→ "hi"

Pipes are one way. →
You can't write to OUT.

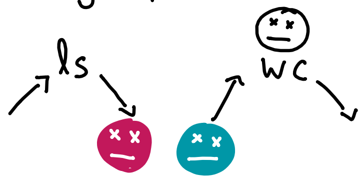
Linux creates a buffer for each pipe.



If data gets written to the pipe faster than it's read, the buffer will fill up. IN OUT

When the buffer is full, writes to IN will block (wait) until the reader reads. This is normal & ok :)

what if your target process dies?



If wc dies, the pipe will close and ls will be sent SIGPIPE. By default, SIGPIPE terminates your process.

named pipes

```
$ mkfifo my-pipe
```

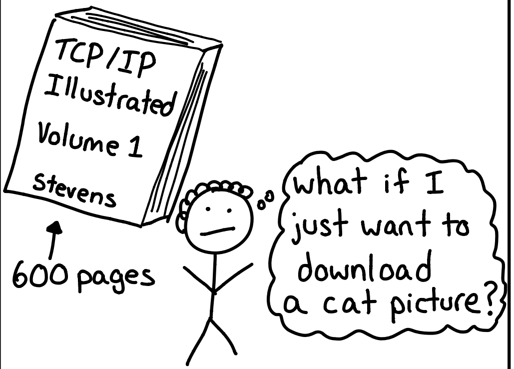
This lets 2 unrelated processes communicate through a pipe!

```
f=open(./my-pipe)
f.write("hi!\n")
```

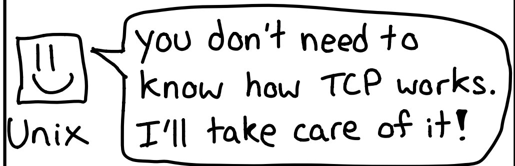
```
f=open(./my-pipe)
f.readline() ← "hi!"
```

sockets

networking protocols are complicated



Unix systems have an API called the "socket API" that makes it easier to make network connections



here's what getting a cat picture with the socket API looks like:

① Create a socket

fd = socket(AF_INET, SOCK_STREAM ...)

② Connect to an IP/port

connect (fd , 12.13.14.15:80)

③ Make a request

write (fd, "GET /cat.png HTTP/1.1 ...)

④ Read the response

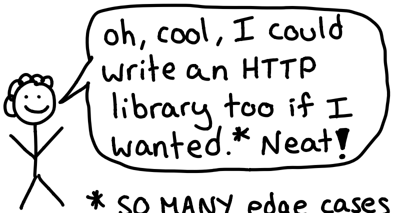
cat_picture = read (fd ...)

Every HTTP library uses sockets under the hood

$ curl awesome.com

Python: requests.get("yay.us")

SOCKETS



* SO MANY edge cases though!

AF_INET? What's that?

AF_INET means basically "internet socket": it lets you connect to other computers on the internet using their IP address.

The main alternative is AF_UNIX ("unix domain socket") for connecting to programs on the same computer.

3 kinds of internet (AF_INET) sockets:

SOCK_STREAM = TCP

curl uses this

SOCK_DGRAM = UDP

dig (DNS) uses this

SOCK_RAW = just let me send IP packets. I will implement my own protocol.

ping uses this

unix domain sockets

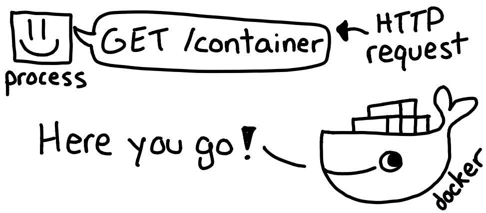
unix domain sockets are files.

$ file mysock.sock
socket

the file's permissions determine who can send data to the socket.

they let 2 programs on the same computer communicate.

Docker uses Unix domain sockets, for example!



There are 2 kinds of unix domain sockets:

stream — like TCP! Lets you send a continuous stream of bytes.

datagram — like UDP! Lets you send discrete chunks of data

advantage 1

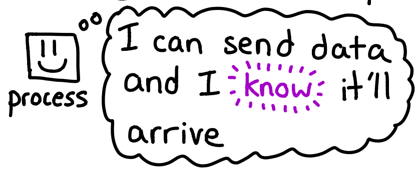
Lets you use file permissions to restrict access to HTTP/database services!

chmod 600 secret.sock

This is why Docker uses a unix domain socket.

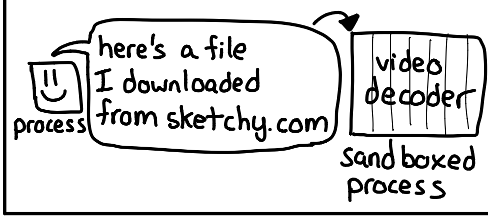
advantage 2

UDP sockets aren't always reliable (even on the same computer).
unix domain datagram sockets are reliable!
And they won't reorder packets!



advantage 3

You can send a file descriptor over a unix domain socket.
Useful when handling untrusted input files!



What's in a process?

PID

process #129 reporting for duty!

USER and GROUP

Who are you running as?

julia!

ENVIRONMENT VARIABLES

like PATH! you can set them with:

$ env A=val ./program

SIGNAL HANDLERS

I ignore SIGTERM!

I shut down safely!

WORKING DIRECTORY

Relative paths (./blah) are relative to the working directory! chdir changes it.

PARENT PID

PID 1 (init) is everyone's ancestor

PID 147

PID 129

COMMAND LINE ARGUMENTS

see them in

/proc/PID/cmdline

OPEN FILES

Every open file has an offset.

I've read 8000 bytes of that one

MEMORY

heap! stack!

shared libraries!

the program's binary!

mmaped files!

THREADS

sometimes one

sometimes LOTS

CAPABILITIES

I have CAP_PTRACE

well I have CAP_SYS_ADMIN

NAMESPACES

I'm in the host network namespace

I have my own namespace!

container process

threads

Threads let a process do many different things at the same time

process:

thread 1: I'm calculating ten million digits of π! so fun!

thread 2: I'm finding a REALLY BIG prime number!

threads in the same process share memory

thread 1: I'll write some digits of π to 0x129420 in memory

thread 2: uh oh! that's where I was putting my prime numbers.

and they share code

calculate_pi

find_big_prime_number

but each thread has its own stack and they can be run by different CPUs at the same time

CPU 1 — π thread

CPU 2 — primes thread

sharing memory can cause problems (race conditions!)

memory

23

thread 1: I'm going to add 1 to that number!

thread 2: I'm going to add 1 to that number!

same time

RESULT: 24 ← WRONG. Should be 25!

why use threads instead of starting a new process?

→ a thread takes less time to create.

→ sharing data between threads is very easy. But it's also easier to make mistakes with threads.

thread 1: you weren't supposed to CHANGE that data!

floating point

a double is 64 bits

sign exponent fraction

10011011 10011011 10011011 10011011
10011011 10011011 10011011 10011011

$$\pm 2^{E-1023} \times 1.\mathrm{frac}$$

That means there are 2^{64} doubles.
The biggest one is about

$$2^{1023}$$

weird double arithmetic

$2^{52}+0.2=2^{52}$ ← (the next number after 2^{52} is $2^{52}+1$)

$1+\frac{1}{2^{54}}=1$ ← (the next number after 1 is $1+\frac{1}{2^{52}}$)

2^{2000} = infinity ← infinity is a double

infinity - infinity = nan ← nan = "not a number"

doubles get farther apart as they get bigger

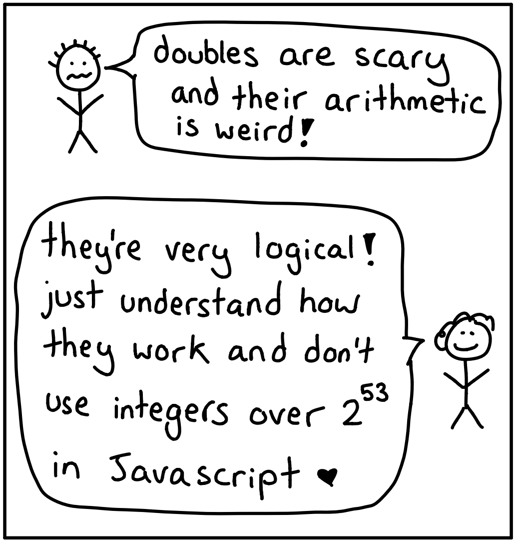
between 2^n and 2^{n+1} there are always 2^{52} doubles, evenly spaced.

that means the next double after 2^{60} is $2^{60}+64$ ← $\frac{2^{60}}{2^{52}}$

Javascript only has doubles (no integers!)

```
> 2**53
9007199254740992
> 2**53 + 1
9007199254740992
```

same number! uh oh!



file buffering

I printed some text but it didn't appear on the screen. why??

time to learn about flushing!

On Linux, you write to files & terminals with the system call

♥ write ♥

process: please write "I ♥ cats" to file #1 (stdout)

Linux: okay!

I/O libraries don't always call write when you print.

```
printf("I ♥ cats");
```

printf: I'll wait for a newline before actually writing

This is called buffering and it helps save on syscalls.

3 kinds of buffering
(defaults vary by library)

1. None. This is the default for stderr.
2. Line buffering. (write after newline). The default for terminals.
3. "full" buffering. (write in big chunks) The default for files and pipes.

flushing

To force your I/O library to write everything it has in its buffer right now, call flush!

stdio: I'll call write right away!!

when it's useful to flush

→ when writing an interactive prompt!

Python example:

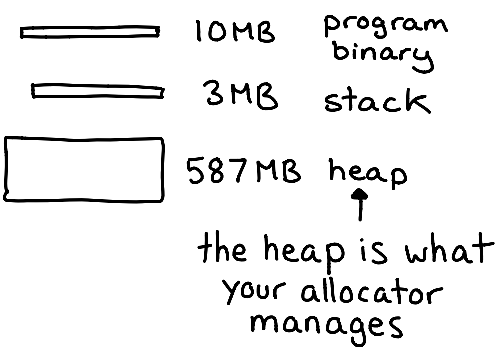
```
print("password: ", flush=True)
```

→ when you're writing to a pipe / socket

program: no seriously, actually write to that pipe please

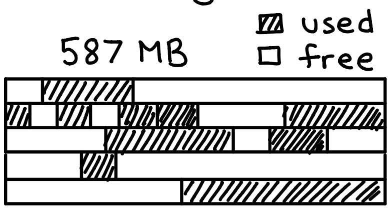
memory allocation

your program has memory

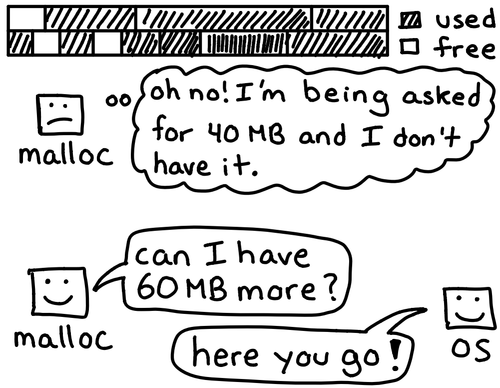


your memory allocator (malloc) is responsible for 2 things.

THING 1: keep track of what memory is used/free.



THING 2: Ask the OS for more memory!



your memory allocator's interface

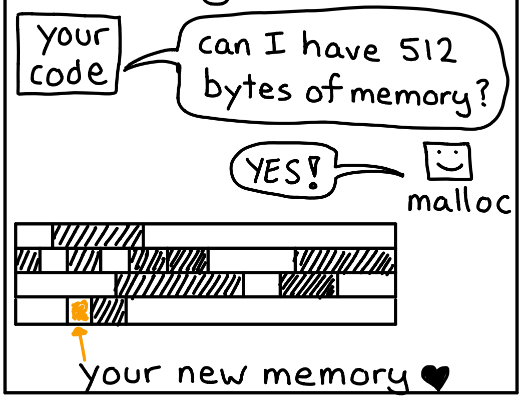
malloc (size_t size)
allocate size bytes of memory & return a pointer to it.

free (void* pointer)
mark the memory as unused (and maybe give back to the OS).

realloc(void* pointer, size_t size)
ask for more/less memory for pointer.

calloc (size_t members, size_t size)
allocate array + initialize to 0.

malloc tries to fill in unused space when you ask for memory



malloc isn't magic!

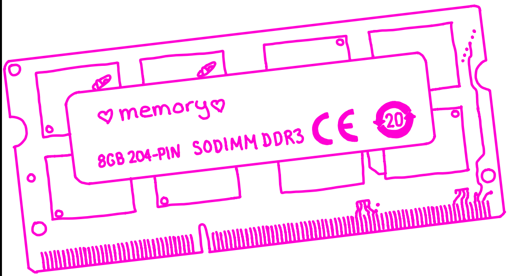
it's just a function!

you can always:

- use a different malloc library like jemalloc or tcmalloc (easy!)
- implement your own malloc (harder)

virtual memory

your computer has physical memory



physical memory has addresses, like

0 - 8GB

but when your program references an address like 0x 5c69a2a2, that's not a physical memory address! It's a virtual address.

every program has its own virtual address space

program 1: 0x 129520 → "puppies"

program 2: 0x 129520 → "bananas"

Linux keeps a mapping from virtual memory pages to physical memory pages called the page table

a "page" is a 4kb chunk of memory — or sometimes bigger

PID	virtual addr	physical addr
1971	0x 20000	0x 192000
2310	0x 20000	0x 228000
2310	0x 21000	0x 9788000

when your program accesses a virtual address

CPU: I'm accessing 0x 21000

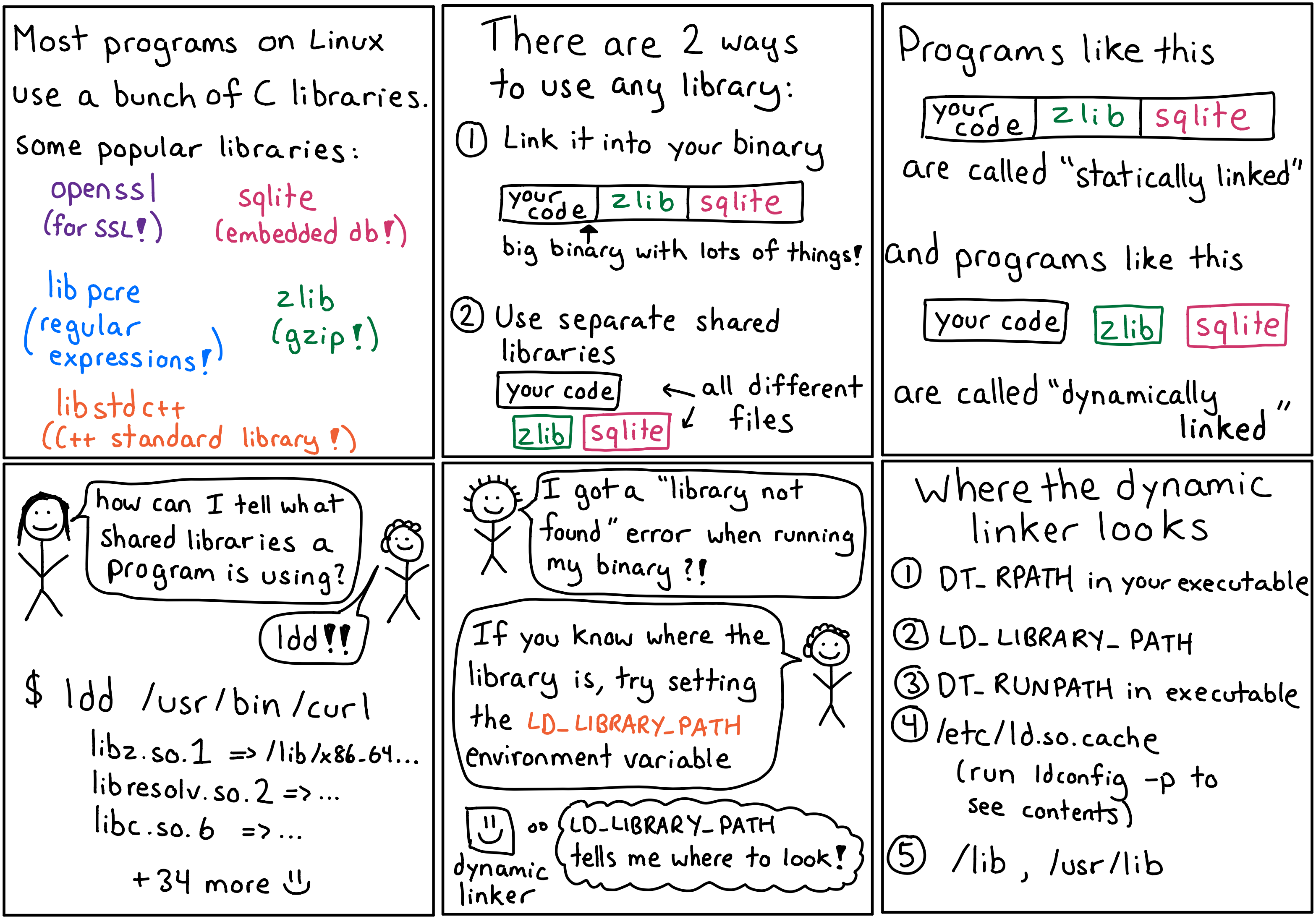
MMU "memory management unit" (hardware): I'll look that up in the page table and then access the right physical address

every time you switch which process is running, Linux needs to switch the page table

Linux: here's the address of process 2950's page table

MMU: thanks, I'll use that now!

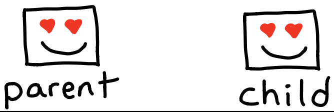
shared libraries



copy on write

On Linux, you start new processes using the fork() or clone() system call.

calling fork creates a child process that's a copy of the caller



the cloned process has EXACTLY the same memory.

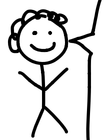
→ same heap

→ same stack

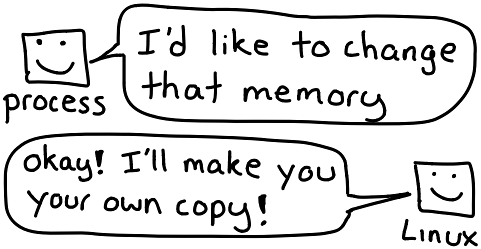
→ same memory maps

if the parent has 3GB of memory, the child will too.

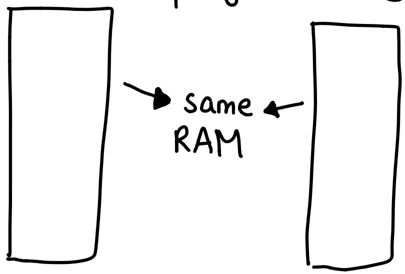
copying all that memory every time we fork would be slow and a waste of RAM



so Linux lets them share physical RAM and only copies the memory when one of them tries to write



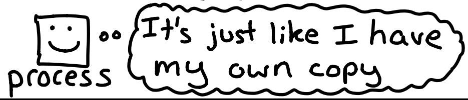
Linux does this by giving both the processes identical page tables.



but it marks every page as read only.

when a process tries to write to a shared memory address:

1. there's a page fault
2. Linux makes a copy of the page & updates the page table
3. the process continues, blissfully ignorant



page faults

every Linux process has a page table

★ page table ★

virtual memory address	physical memory address
0x19723000	0x1422000
0x19724000	0x1423000
0x1524000	not in memory
0x1844000	0x4a000 read only

some pages are marked as either

★ read only

★ not resident in memory

when you try to access a page that's marked "not resident in memory", it triggers a ! page fault !

what happens during a page fault?

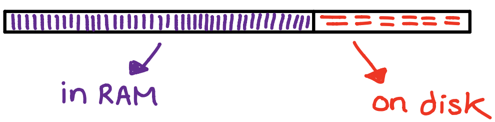
→ the MMU sends an interrupt

→ your program stops running

→ Linux kernel code to handle the page fault runs

Linux: I'll fix the problem and let your program keep running

"not resident in memory" usually means the data is on disk!



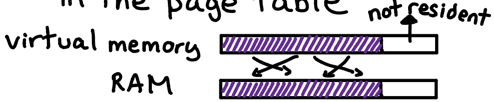
Having some virtual memory that is actually on disk is how swap and mmap work.

how swap works

① run out of RAM

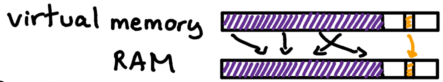
② Linux saves some RAM data to disk

③ mark those pages as "not resident in memory" in the page table



④ When a program tries to access the memory, there's a ! page fault !

⑤ Linux: time to move some data back to RAM!



⑥ if this happens a lot, your program gets VERY SLOW

I'm always waiting for data to be moved in & out of RAM

mmap

what's mmap for?

I want to work with a VERY LARGE FILE but it won't fit in memory

you could try mmap!

(mmap = "memory map")

load files lazily with mmap

When you mmap a file, it gets mapped into your program's memory.

2TB file ← 2 TB of virtual memory

but nothing is ACTUALLY read into RAM until you try to access the memory.
(how it works: page faults!)

how to mmap in Python

```
import mmap
f= open("HUGE.txt")
mm= mmap.mmap(f.fileno(), 0)
```

↑ this won't read the file from disk! Finishes ~instantly.

```
print (mm[-1000:])
```

↑ this will read only the last 1000 bytes!

sharing big files with mmap

we all want to read the same file!

no problem! — mmap

Even if 10 processes mmap a file, it will only be read into memory ♥ once ♥

dynamic linking uses mmap

program: I need to use libc.so.6

↑ C standard library

ld (dynamic linker): you too eh? no problem. I always mmap, so that file is probably loaded into memory already.

anonymous memory maps

→ not from a file (memory set to 0 by default)

→ with MAP_SHARED, you can use them to share memory with a subprocess!

man page sections

man pages are split up into 8 sections

① ② ③ ④ ⑤ ⑥ ⑦ ⑧

$ man 2 read

means "get me the man page for read from section 2".

There's both
→ a program called "read"
→ and a system call called "read"

so

$ man 1 read

gives you a different man page from

$ man 2 read

If you don't specify a section, man will look through all the sections & show the first one it finds.

man page sections

① programs

$ man grep
$ man ls

② system calls

$ man sendfile
$ man ptrace

③ C functions

$ man printf
$ man fopen

④ devices

$ man null
for /dev/null docs

⑤ file formats

$ man sudoers
for /etc/sudoers
$ man proc
files in /proc!

⑥ games

not super useful.
$ man sl
is my favourite from that section

⑦ miscellaneous

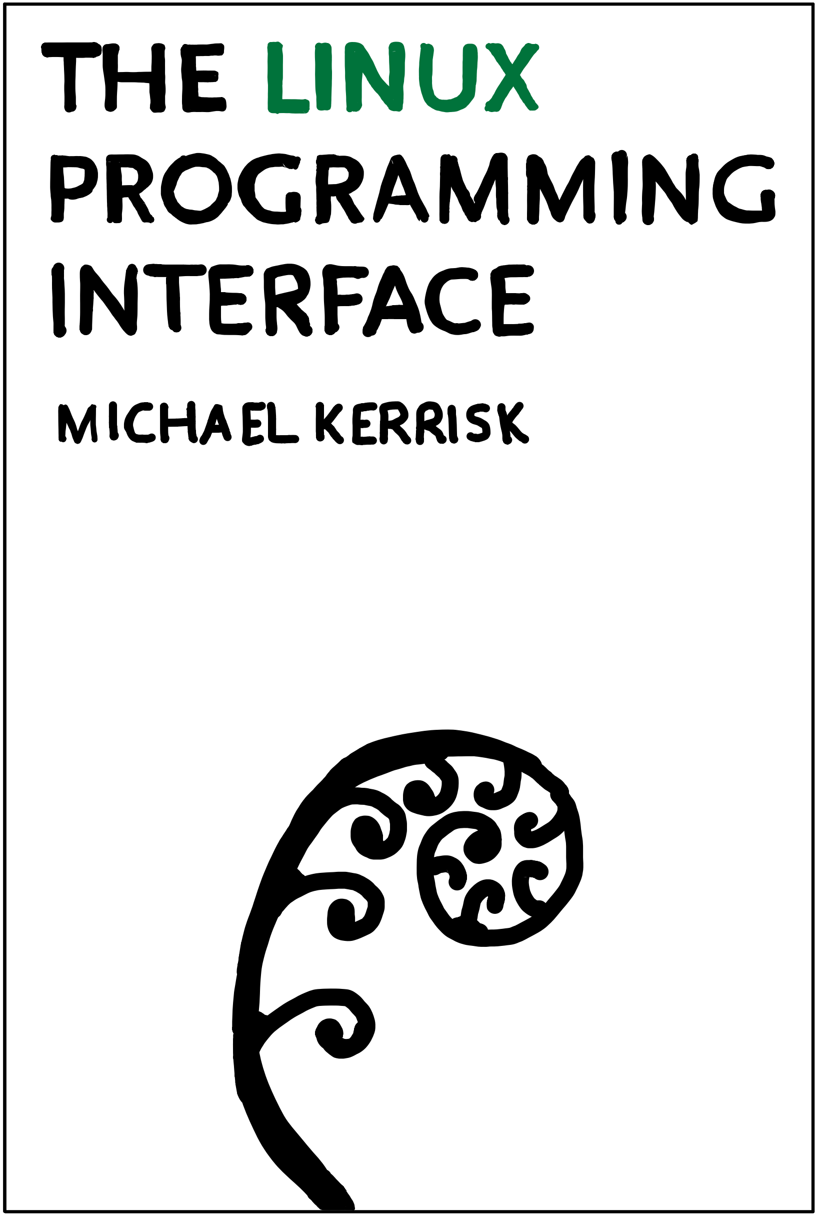
explains concepts!

$ man 7 pipe
$ man 7 symlink

⑧ sysadmin programs

$ man apt
$ man chroot

Want to learn more?
I highly recommend
this book: →



Every chapter is a readable, short (usually 10-20 pages) explanation of a Linux system.

I used it as a reference <u>constantly</u> when writing this zine.

I ♡ it because even though it's huge and comprehensive (1500 pages!), the chapters are short and self-contained and it's very easy to pick it up and learn something.