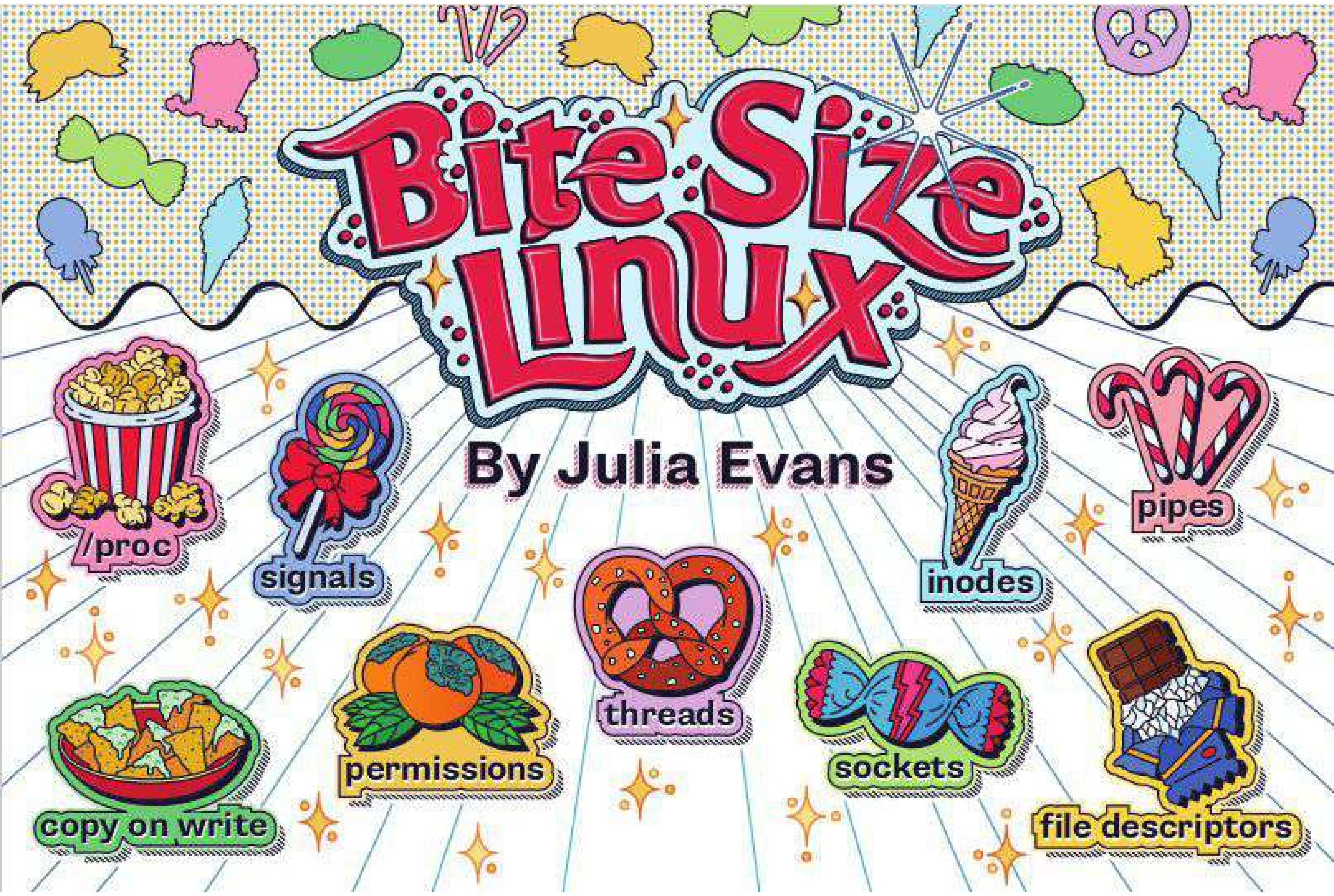
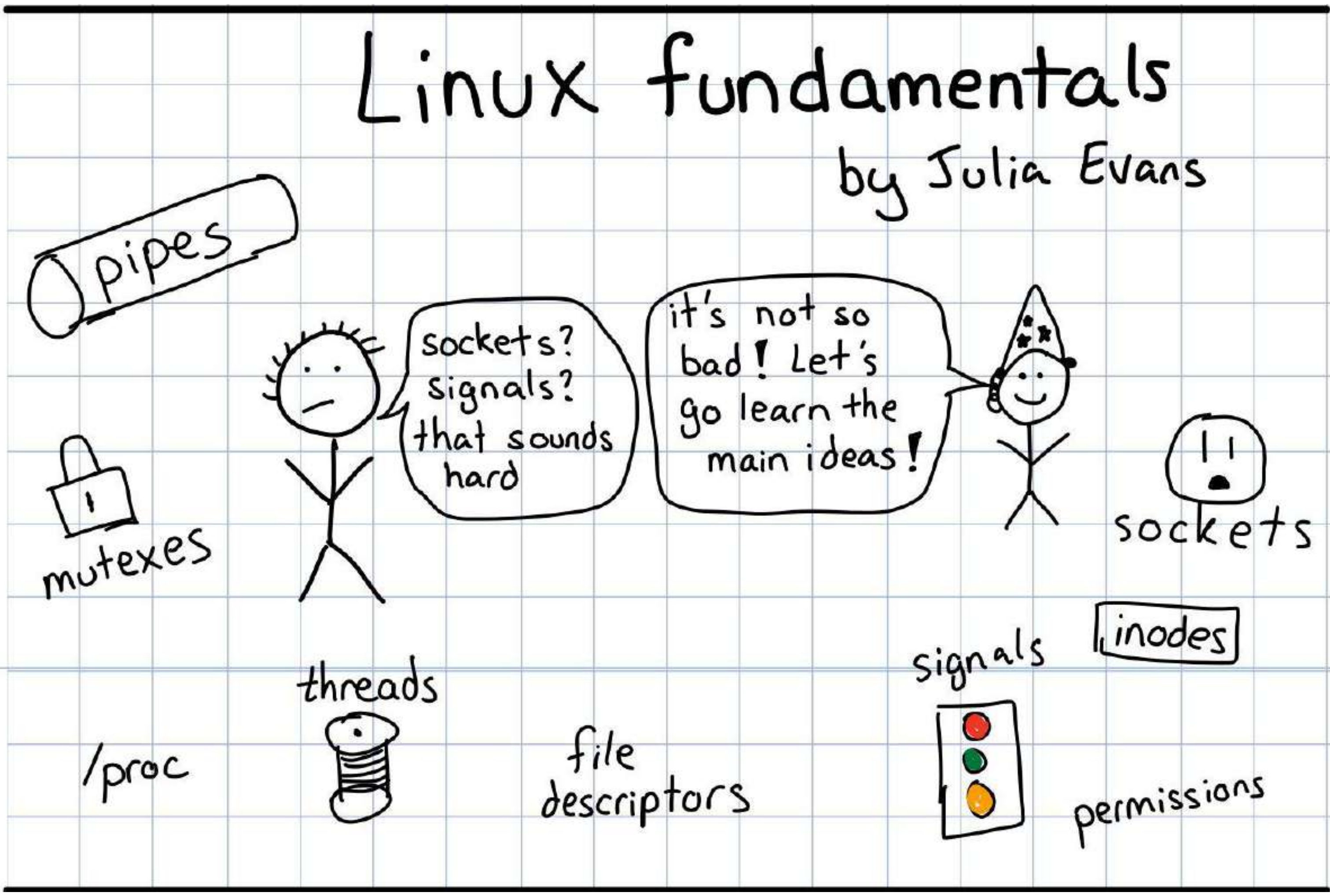


Bite Size Linux
By Julia Evans
/proc
signals
inodes
pipes
threads
copy on write
permissions
sockets
file descriptors

♥ Table of contents ♥


Linux fundamentals
by Julia Evans
pipes
sockets? signals? that sounds hard
it's not so bad! Let's go learn the main ideas!
mutexes
sockets
inodes
signals
threads
/proc
file descriptors
permissions

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unix permissions

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There are 3 things you can do to a file

read write execute

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 the r/w/x bits:

1 means "allowed"

0 means "not allowed"

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!

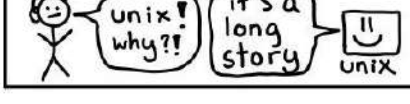
setuid affects executables

$ ls -l /bin/ping

rws r-x r-x root root

this means ping <u>always</u> runs as root

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



an amazing directory: /proc

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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

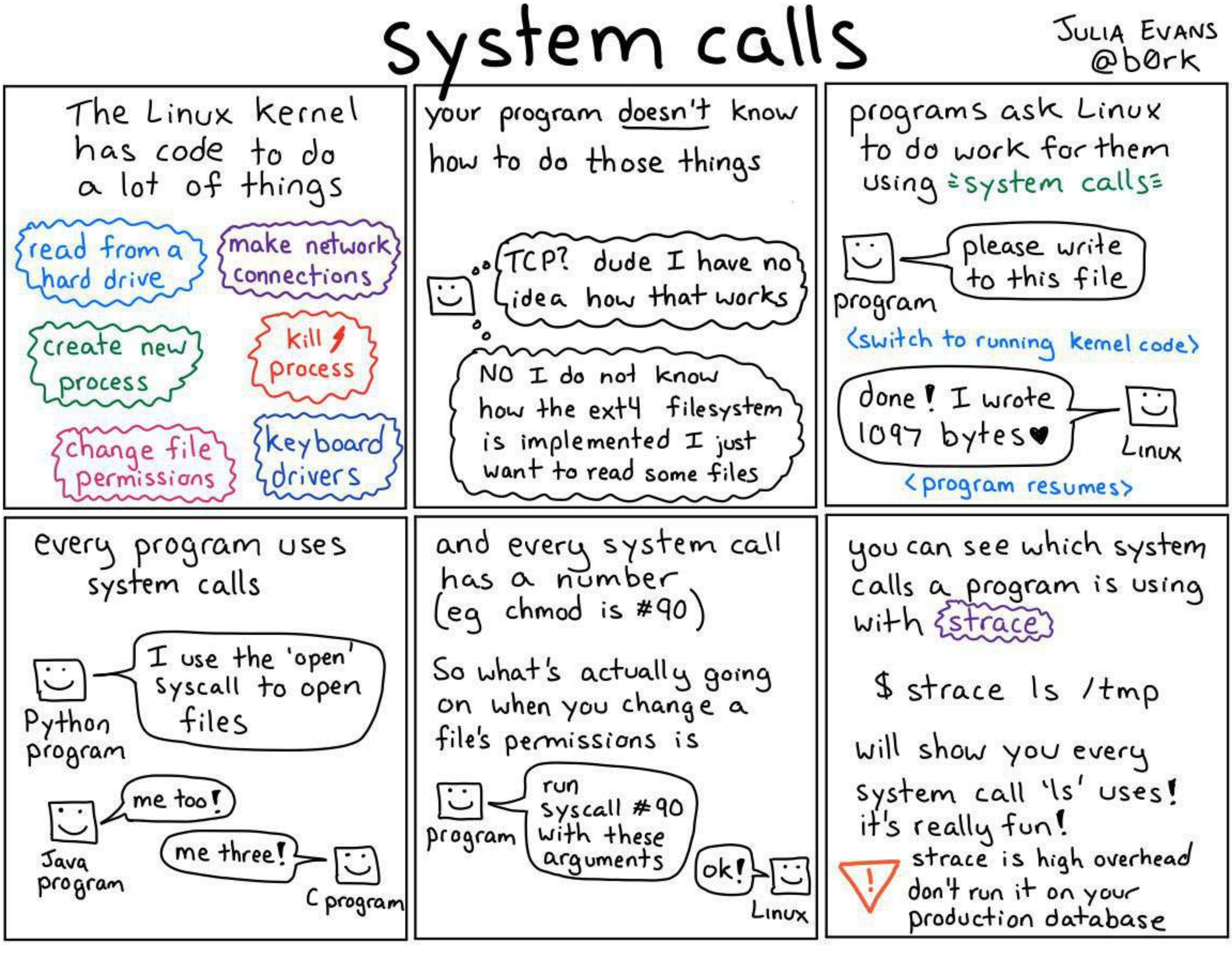
List of process's memory maps. Shared libraries, heap, anonymous maps, etc.

and more

Look at

man proc

for more information!


system calls
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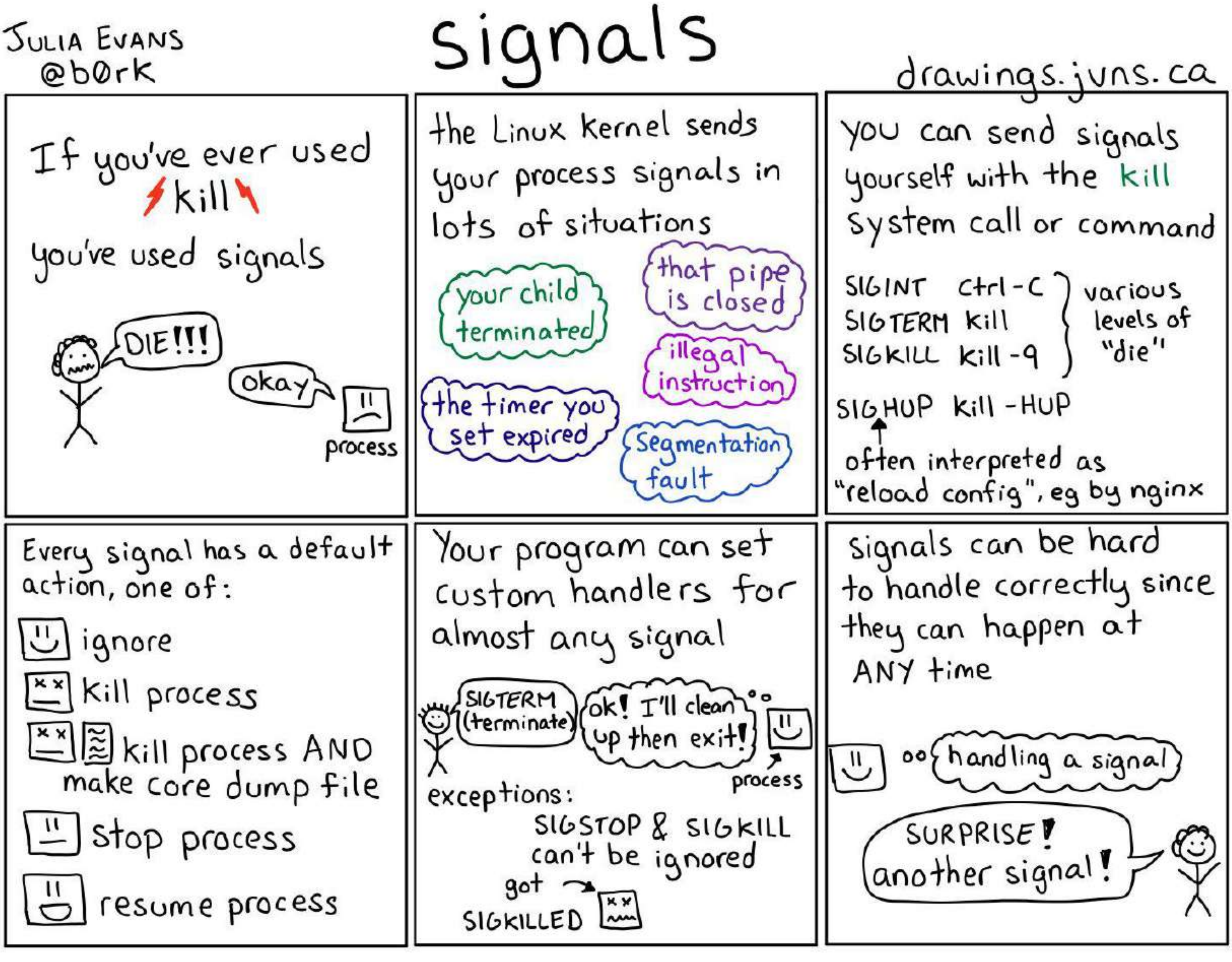
The Linux kernel has code to do a lot of things
read from a hard drive
make network connections
create new process
kill process
change file permissions
keyboard drivers
your program doesn't know how to do those things
TCP? dude I have no idea how that works
NO I do not know how the ext4 filesystem is implemented I just want to read some files
programs ask Linux to do work for them using system calls
please write to this file
program
<switch to running kernel code>
done! I wrote 1097 bytes♥
Linux
<program resumes>
every program uses system calls
I use the 'open' syscall to open files
Python program
me too!
Java program
me three!
C program
and every system call has a number (eg chmod is #90)
So what's actually going on when you change a file's permissions is
run syscall #90 with these arguments
program
ok!
Linux
you can see which system calls a program is using with strace
$ strace ls /tmp
will show you every system call 'ls' uses! it's really fun!
strace is high overhead don't run it on your production database



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signals
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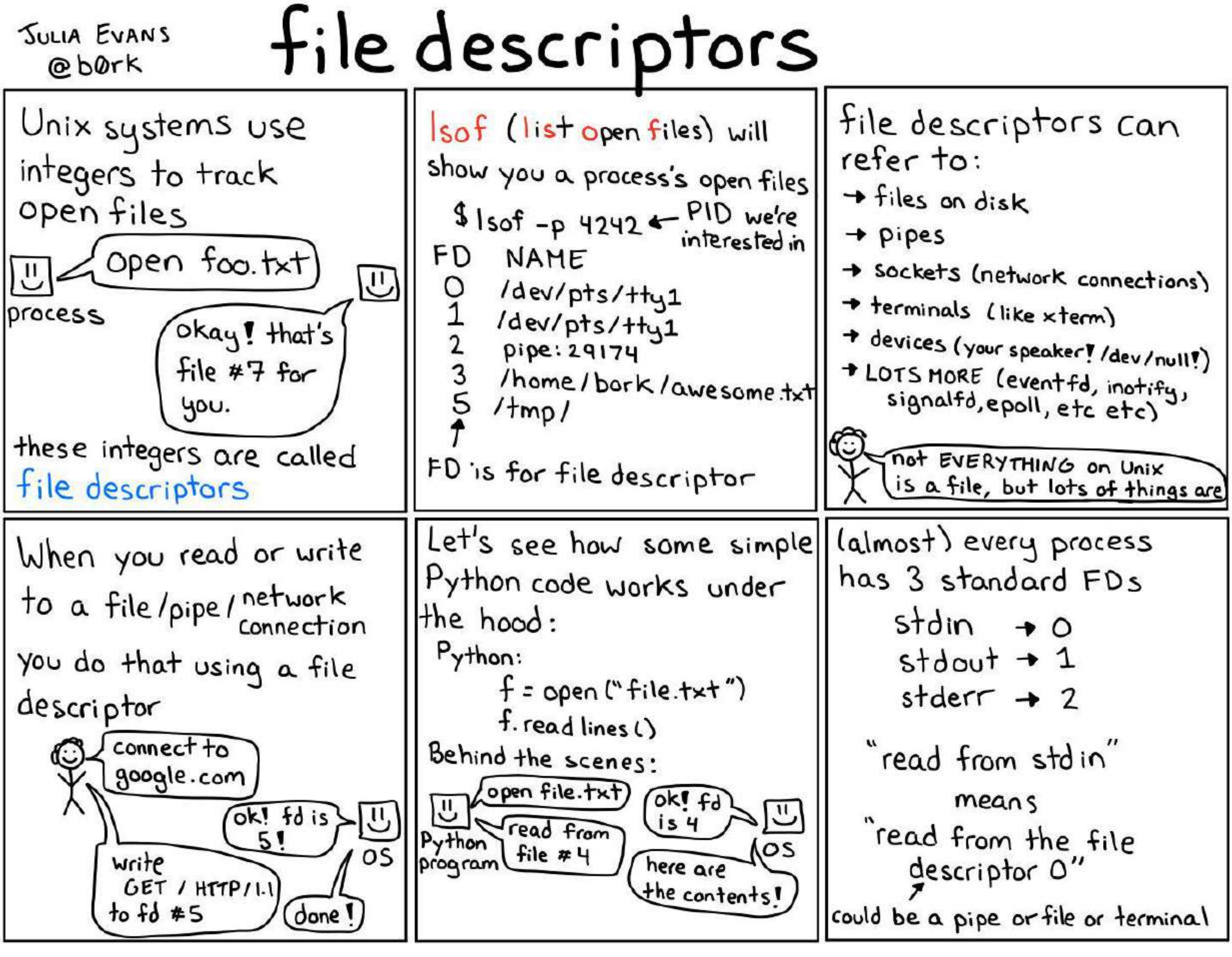
If you've ever used kill you've used signals
DIE!!!
okay
process
the Linux kernel sends your process signals in lots of situations
your child terminated
that pipe is closed
illegal instruction
the timer you set expired
segmentation fault
you can send signals yourself with the kill system call or command
SIGINT Ctrl-C
SIGTERM kill
SIGKILL kill -9
various levels of "die"
SIGHUP kill -HUP
often interpreted as "reload config", eg by nginx
Every signal has a default action, 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
SIGTERM (terminate)
ok! I'll clean up then exit!
process
exceptions:
SIGSTOP & SIGKILL can't be ignored
got SIGKILLED
signals can be hard to handle correctly since they can happen at ANY time
handling a signal
SURPRISE! another signal!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file descriptors
Unix systems use integers to track open files
open foo.txt
process
okay! that's file #7 for you.
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 etc)
not EVERYTHING on Unix is a file, but lots of things are
When you read or write to a file/pipe/network connection you do that using a file descriptor
connect to google.com
ok! fd is 5!
OS
write GET / HTTP/1.1 to fd #5
done!
Let's see how some simple Python code works under the hood:
Python:
f = open("file.txt")
f.readlines()
Behind the scenes:
open file.txt
ok! fd is 4
Python program
read from file #4
OS
here are the contents!
(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

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pipes

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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

IN and OUT

stdin → ls → IN → OUT → wc → stdout

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

ls → IN [buffer: data waiting to be read] OUT → wc

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

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?

ls → IN OUT → wc

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

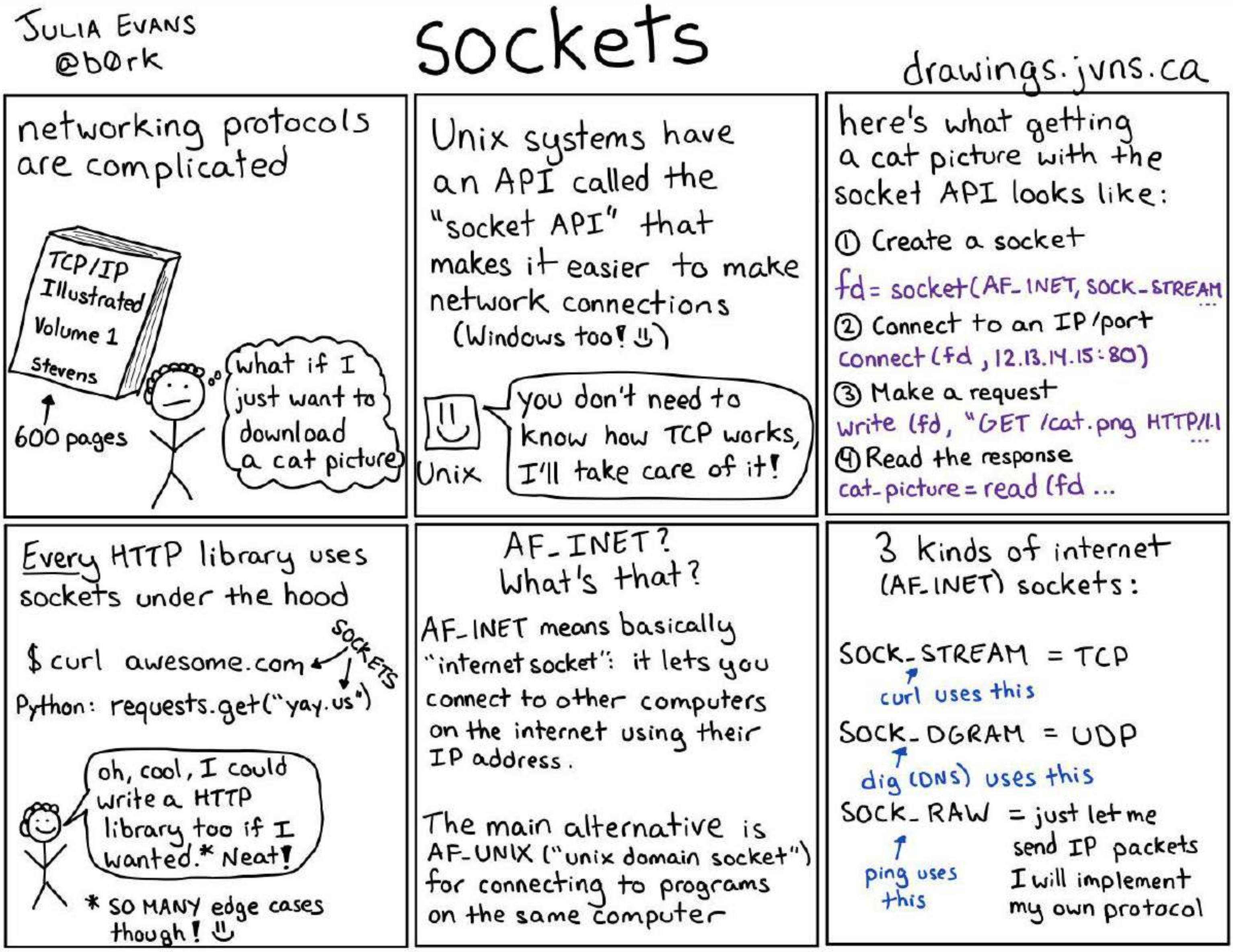
named pipes

$ 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!"
```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sockets
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networking protocols are complicated
TCP/IP Illustrated Volume 1 Stevens
600 pages
what if I just want to download a cat picture
Unix systems have an API called the "socket API" that makes it easier to make network connections
(Windows too! :))
Unix
you don't need to know how TCP works, I'll take care of it!
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
SOCKETS
Python: requests.get("yay.us")
oh, cool, I could write a HTTP library too if I wanted.* Neat!
* 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

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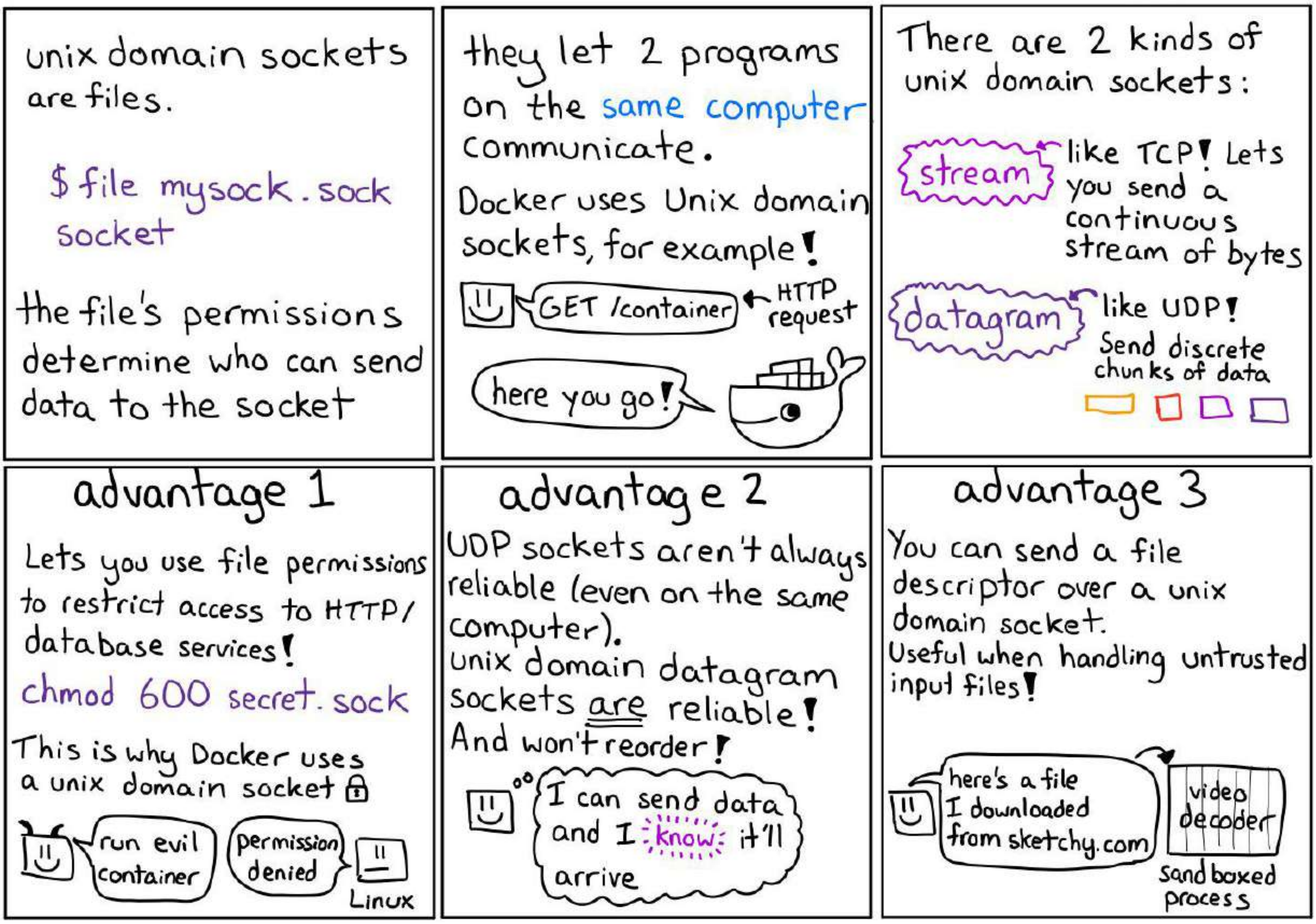

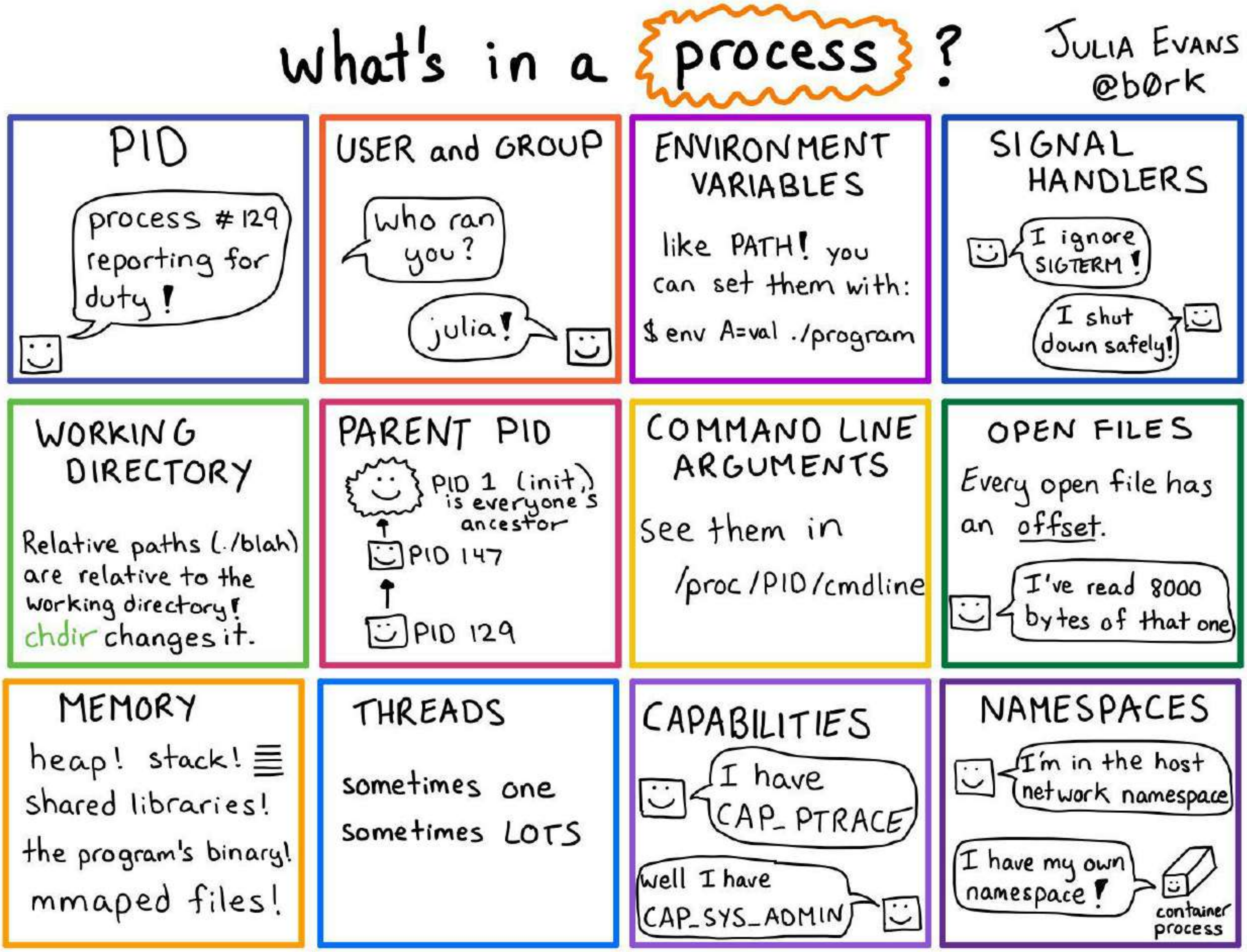
What's in a process?
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PID
process #129 reporting for duty!
USER and GROUP
who ran you?
julia!
ENVIRONMENT VARIABLES
like PATH! you can set them with:
$ env A=val ./program
SIGNAL HANDLERS
I ignore SIGTERM!
I shut down safely!
WORKING DIRECTORY
Relative 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

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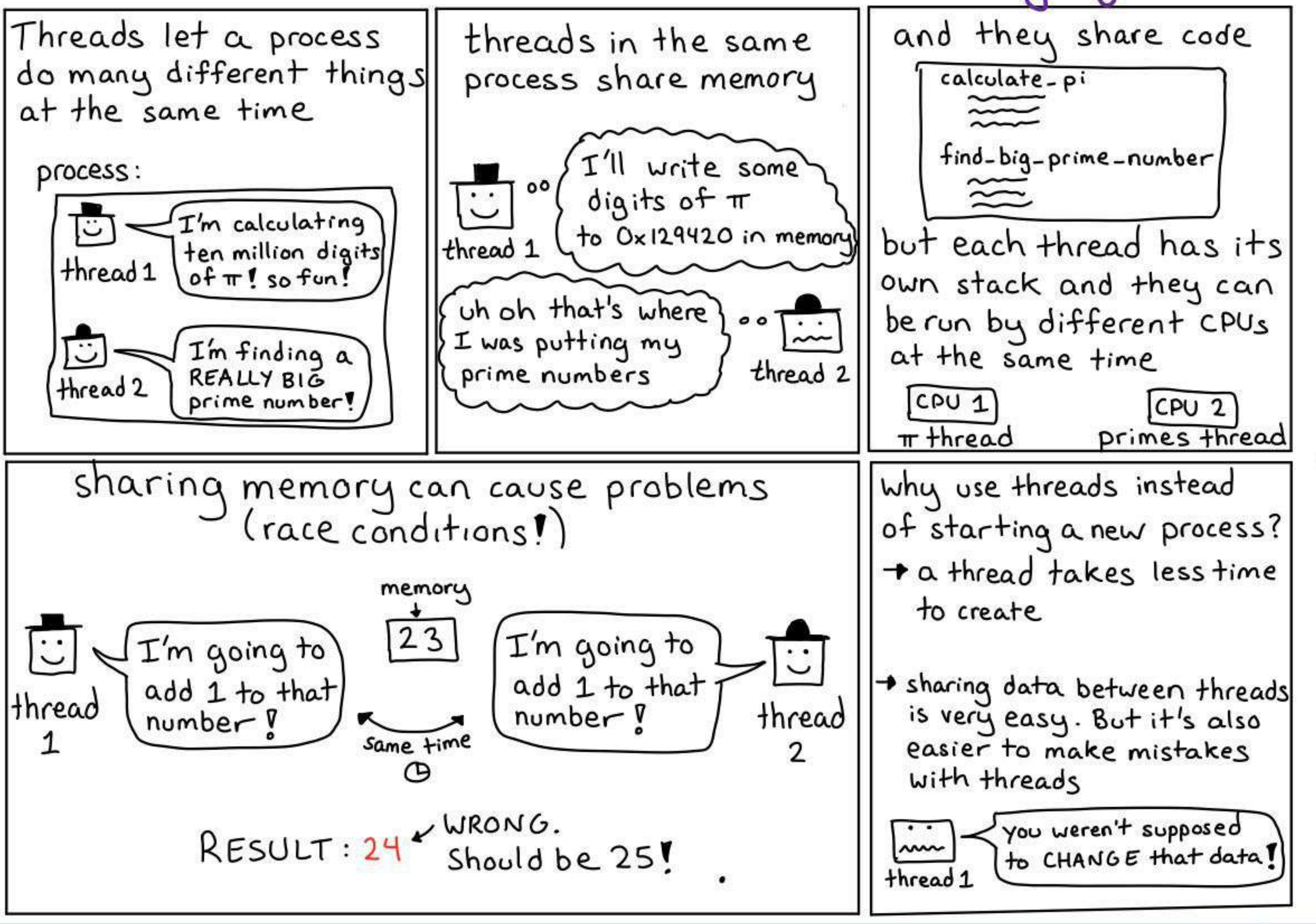

floating point

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a double is 64 bits

sign exponent fraction

10011011 10011011 10011011 10011011
10011011 10011011 10011011 10011011

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

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

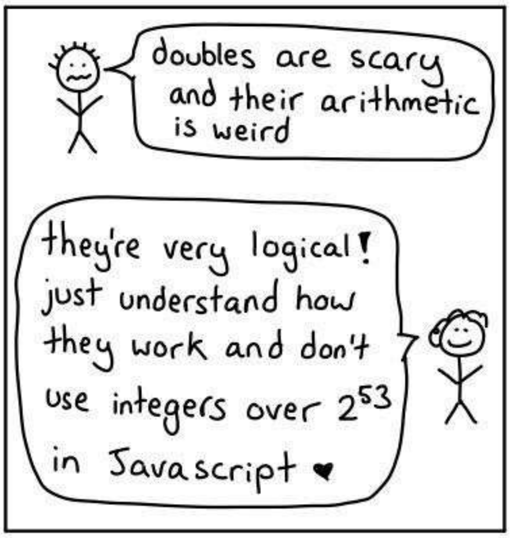
that means the next double after 2^{60} is $2^{60}+64$ ← $\frac{2^{60}}{2^{52}}$

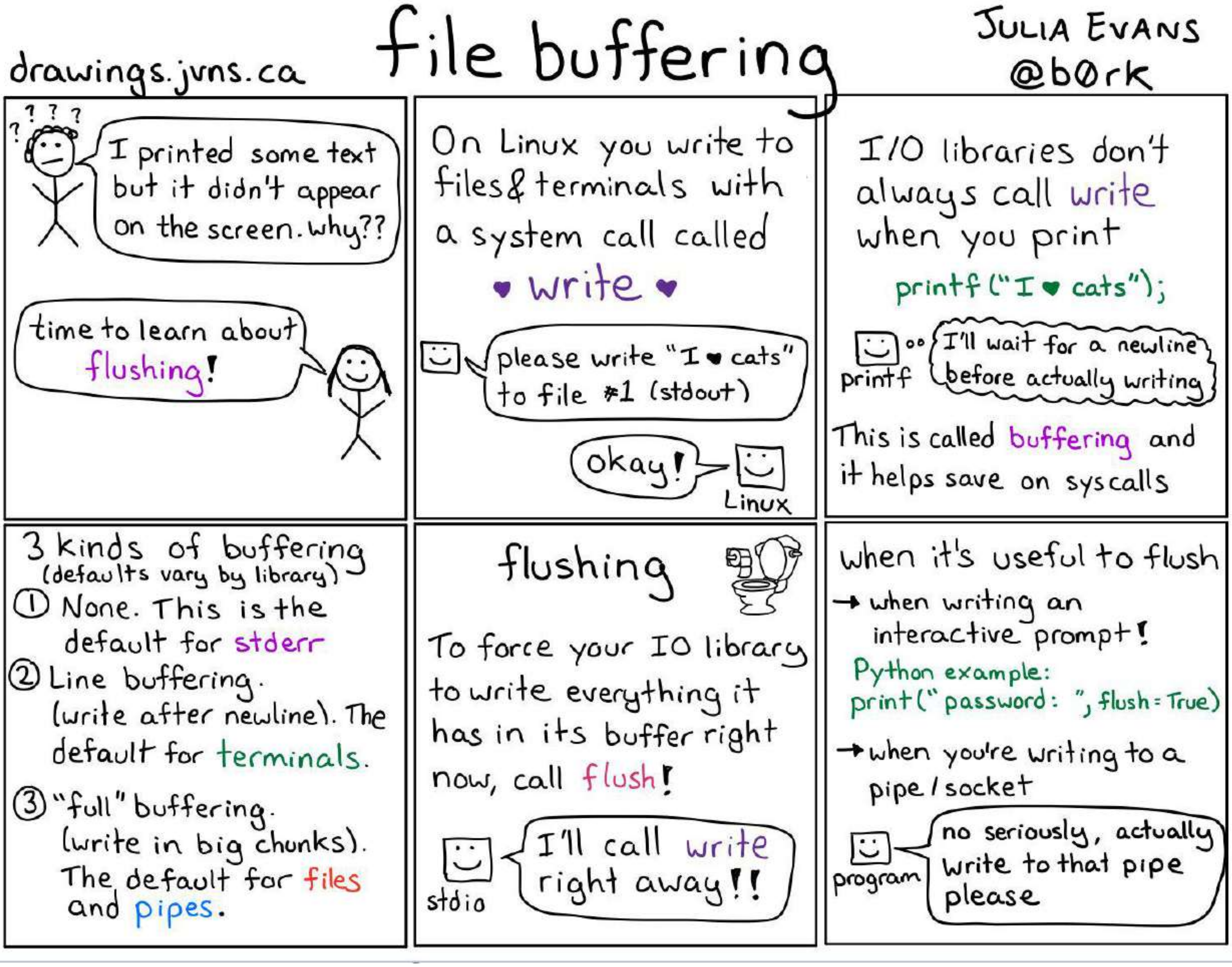
Javascript only has doubles (no integers!)

```
> 2**53
9007199254740992

> 2**53 + 1
9007199254740992
```

same number! uh oh!





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file buffering
JULIA EVANS
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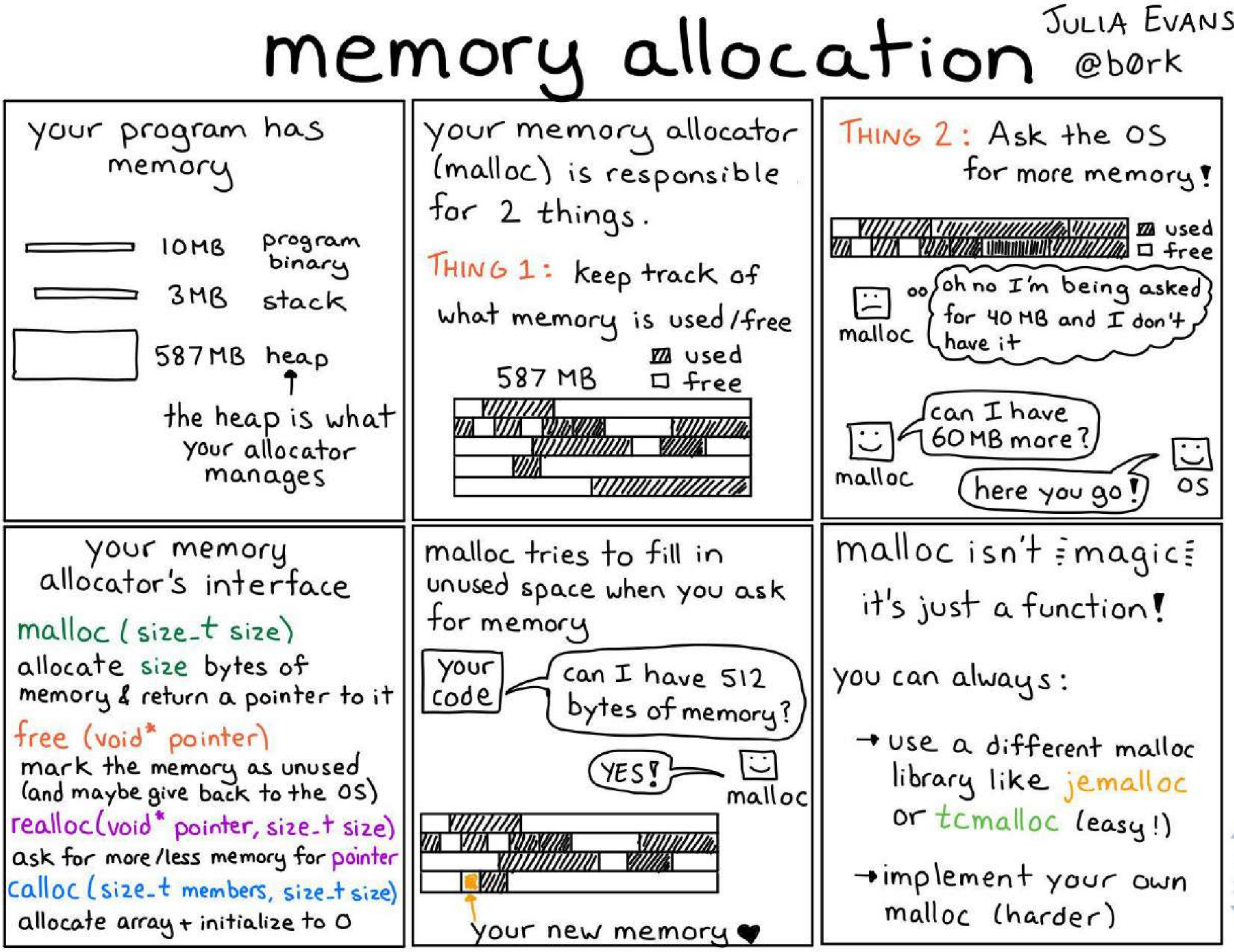
???
I printed some text but it didn't appear on the screen. why??
time to learn about flushing!
On Linux you write to files & terminals with a system call called
♥ write ♥
please write "I ♥ cats" to file #1 (stdout)
okay!
Linux
I/O libraries don't always call write when you print
printf("I ♥ cats");
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 IO 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
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your program has memory
10MB program binary
3MB stack
587MB heap
the heap is what your allocator manages
your memory allocator (malloc) is responsible for 2 things.
THING 1: keep track of what memory is used/free
587 MB
used
free
THING 2: Ask the OS for more memory!
used
free
malloc
oh no I'm being asked for 40 MB and I don't have it
malloc
can I have 60 MB more?
here you go!
OS
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
your code
can I have 512 bytes of memory?
YES!
malloc
your new 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

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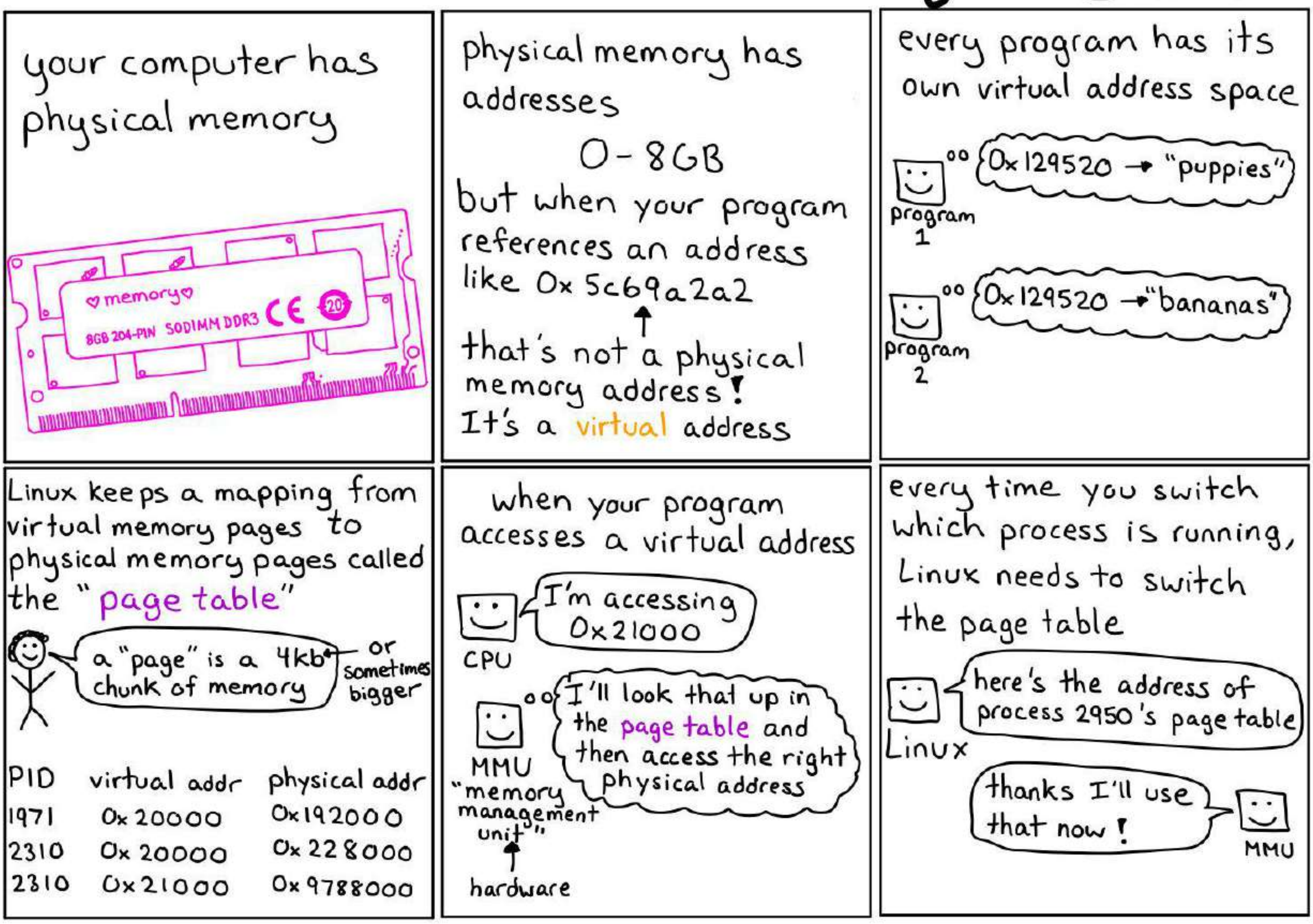

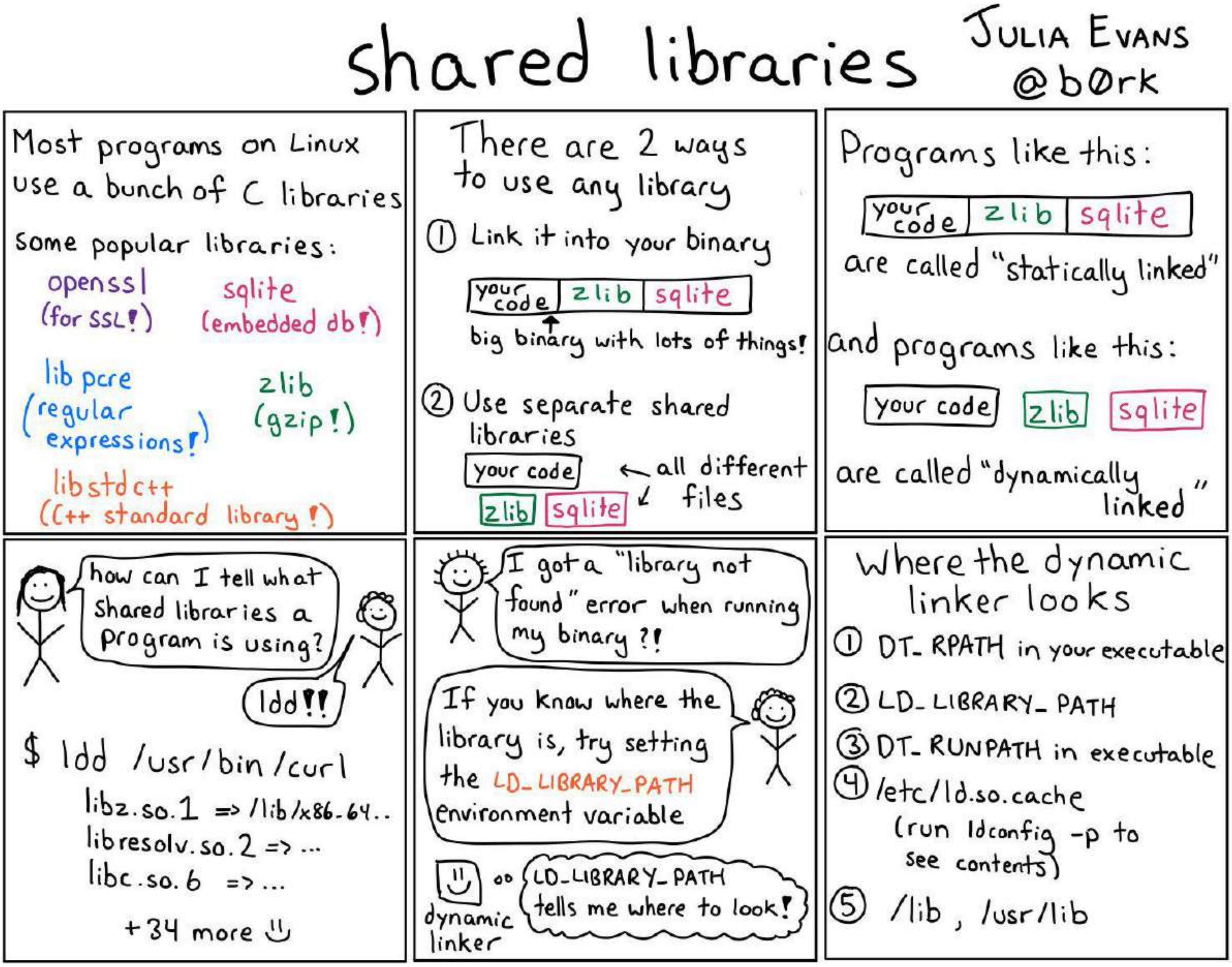
shared libraries
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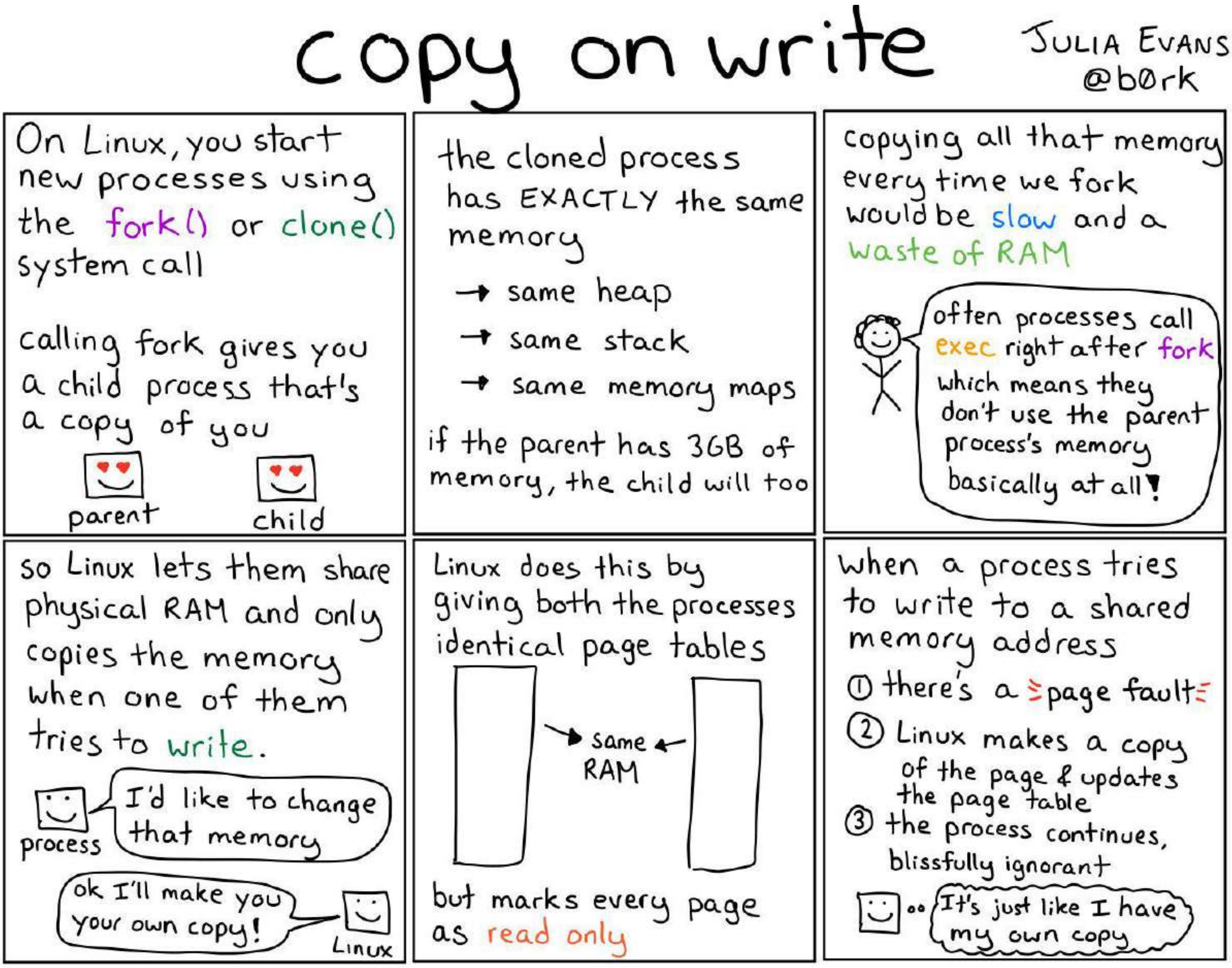
Most programs on Linux use a bunch of C libraries
some popular libraries:
openssl (for SSL!)
sqlite (embedded db!)
lib pcre (regular expressions!)
zlib (gzip!)
libstdc++ (C++ standard library!)
There are 2 ways to use any library
① Link it into your binary
your code
zlib
sqlite
big binary with lots of things!
② Use separate shared libraries
your code
zlib
sqlite
all different files
Programs like this:
your code
zlib
sqlite
are called "statically linked"
and programs like this:
your code
zlib
sqlite
are called "dynamically linked"
how can I tell what shared libraries a program is using?
ldd!!
$ ldd /usr/bin/curl
libz.so.1 => /lib/x86-64..
libresolv.so.2 => ...
libc.so.6 => ...
+34 more
I got a "library not found" error when running my binary ?!
If you know where the library is, try setting the LD_LIBRARY_PATH environment variable
LD_LIBRARY_PATH tells me where to look!
dynamic linker
Where the dynamic linker looks
① DT_RPATH in your executable
② LD_LIBRARY_PATH
③ DT_RUNPATH in executable
④ /etc/ld.so.cache (run ldconfig -p to see contents)
⑤ /lib, /usr/lib


copy on write
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On Linux, you start new processes using the fork() or clone() system call
calling fork gives you a child process that's a copy of you
parent
child
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
often processes call exec right after fork which means they don't use the parent process's memory basically at all!
so Linux lets them share physical RAM and only copies the memory when one of them tries to write.
process
I'd like to change that memory
ok I'll make you your own copy!
Linux
Linux does this by giving both the processes identical page tables
same RAM
but 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
It's just like I have my own copy

page faults

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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 in memory", that triggers a ❗ page fault ❗

what happens during a page fault?

→ the MMU sends an interrupt

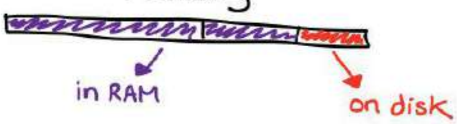
→ your program stops running

→ Linux kernel code to handle the page fault runs

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

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

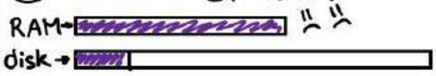
virtual memory



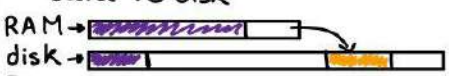
Having some virtual memory that is actually on disk is how swap and mmap work

how swap works

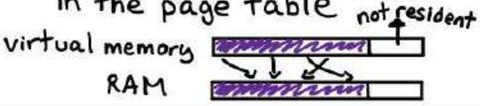
① run out of RAM



② Linux saves some RAM data to disk



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

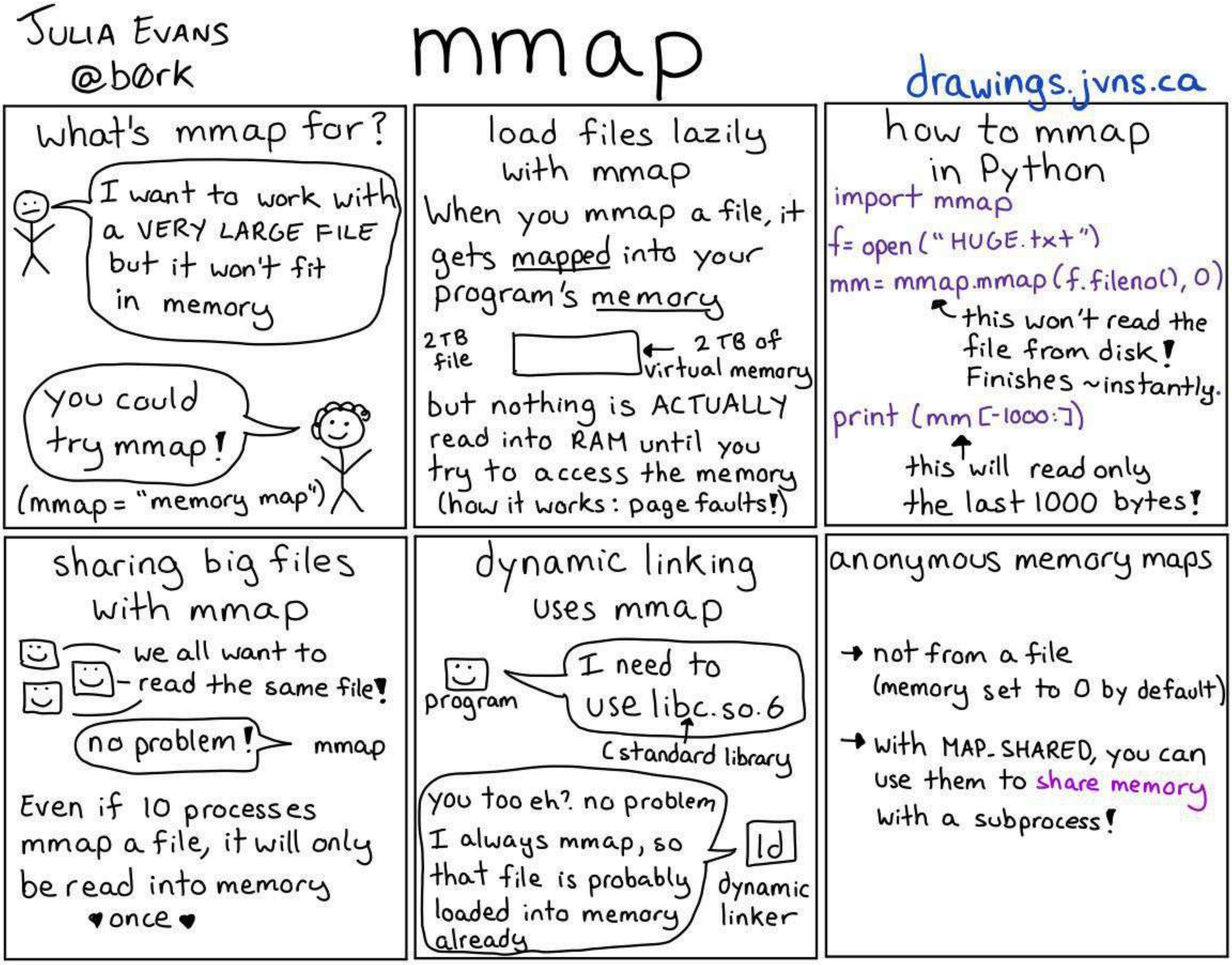


④ When a program tries to access the memory there's a ❗ page fault ❗

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



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mmap
drawings.jvns.ca
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
you too eh? no problem I always mmap, so that file is probably loaded into memory already
ld
dynamic linker
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 pages = awesome

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@b0rk

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 funny if you have sl though.

⑦ miscellaneous
explains concepts!
$ man 7 pipe
$ man 7 symlink

⑧ sysadmin programs
$ man apt
$ man chroot