Carnegie Mellon University

Filesystems — Interface

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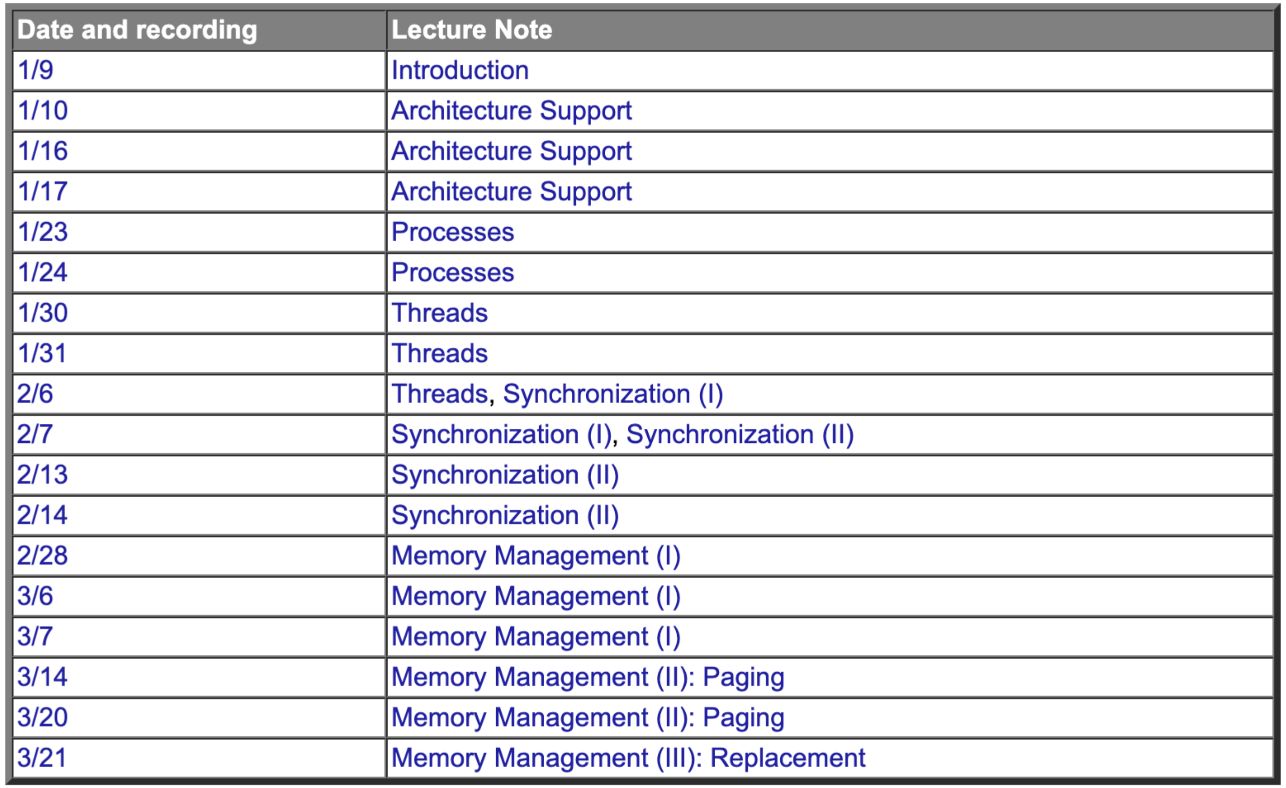
Slides:
saramcallister.github.io/files/2025-03-27-files.pdf

Situating this lecture – Operating Systems (ECE 344)



Date and recording	Lecture Note
1/9	Introduction
1/10	Architecture Support
1/16	Architecture Support
1/17	Architecture Support
1/23	Processes
1/24	Processes
1/30	Threads
1/31	Threads
2/6	Threads, Synchronization (I)
2/7	Synchronization (I), Synchronization (II)
2/13	Synchronization (II)
2/14	Synchronization (II)
2/28	Memory Management (I)
3/6	Memory Management (I)
3/7	Memory Management (I)
3/14	Memory Management (II): Paging
3/20	Memory Management (II): Paging
3/21	Memory Management (III): Replacement

What we’ve covered so far:

Processes

Threads

Storage Devices

Hard disk drives

Cycle-head-sector (CHS) addressing

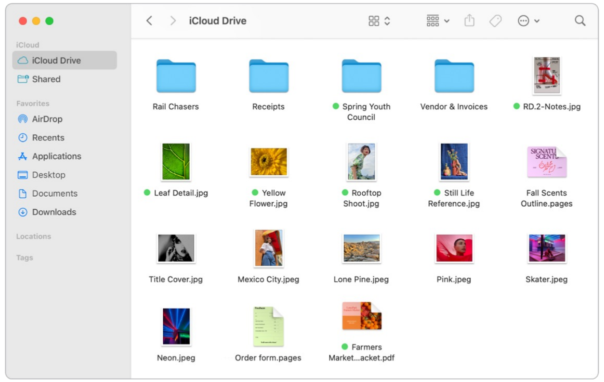
Logical block addresses (LBAs)

0	1	2	3	4

How can we abstract storage devices?

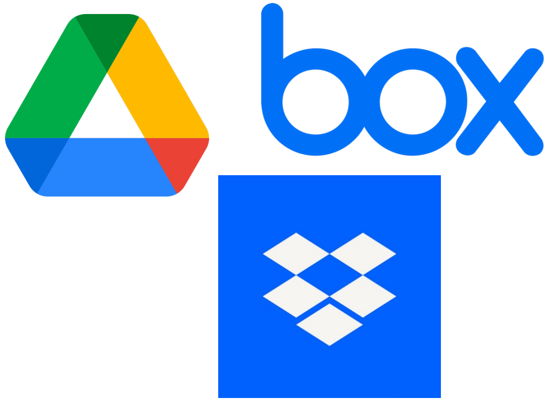
How do we abstract persistent storage?

Filesystems: a system for organizing, managing, and accessing *files* and *directories* stored on persistent media



Local filesystems (UNIX)

Enable



File sharing platforms

Why do we need filesystems?

- Durability across restarts and crashes
- Naming and organization
- Sharing data between processes and users

What makes filesystems challenging?

- Crash recovery (next lecture)
- **Performance + concurrency**
- **Sharing + security**

What we’re covering today: Filesystem interface

What are files?

`open` and fds

Directories and ownership

What are files?

A file is a sequence of bytes, logically grouped together

- Allow users/ processes to access all files the same way

In UNIX, “Everything is a file”

- `/dev/sda2` (disk partition)
- `/dev/tty2` (terminal)
- `/proc/$$/status` (current process status)

Typical file metadata

Name - 14 characters? 8.3? 255?

Identifier - “file number” (usually internal)

Size - two meanings (next lecture)

Protection - Who can do what?

Time, date, last modifier - monitoring, cleaning up

Operations on Files

Write, Read - often via position pointer/ “cursor”

Seek - adjust position pointer for next access

Append - write at end of file (implicit synchronization)

Rename - change name of file inside directory and (maybe) move a file between 2 directories

I/O to a file

Need to read and write to a file

So how do you read and write to one?

Try 1: `read(“example.txt”, buffer, num_bytes);`

- What if the file is large?

I/O to a file

Need to read and write to a file

So how do you read and write to one?

Try 1: `read(“example.txt”, buffer, num_bytes);`

- What if the file is large?

Try 2: `read(“example.txt”, buffer, num_bytes, start_loc);`

- What is notably inefficient about this?
- What’s the solution?

What we're covering today: Filesystem interface

What are files?

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Directories and ownership

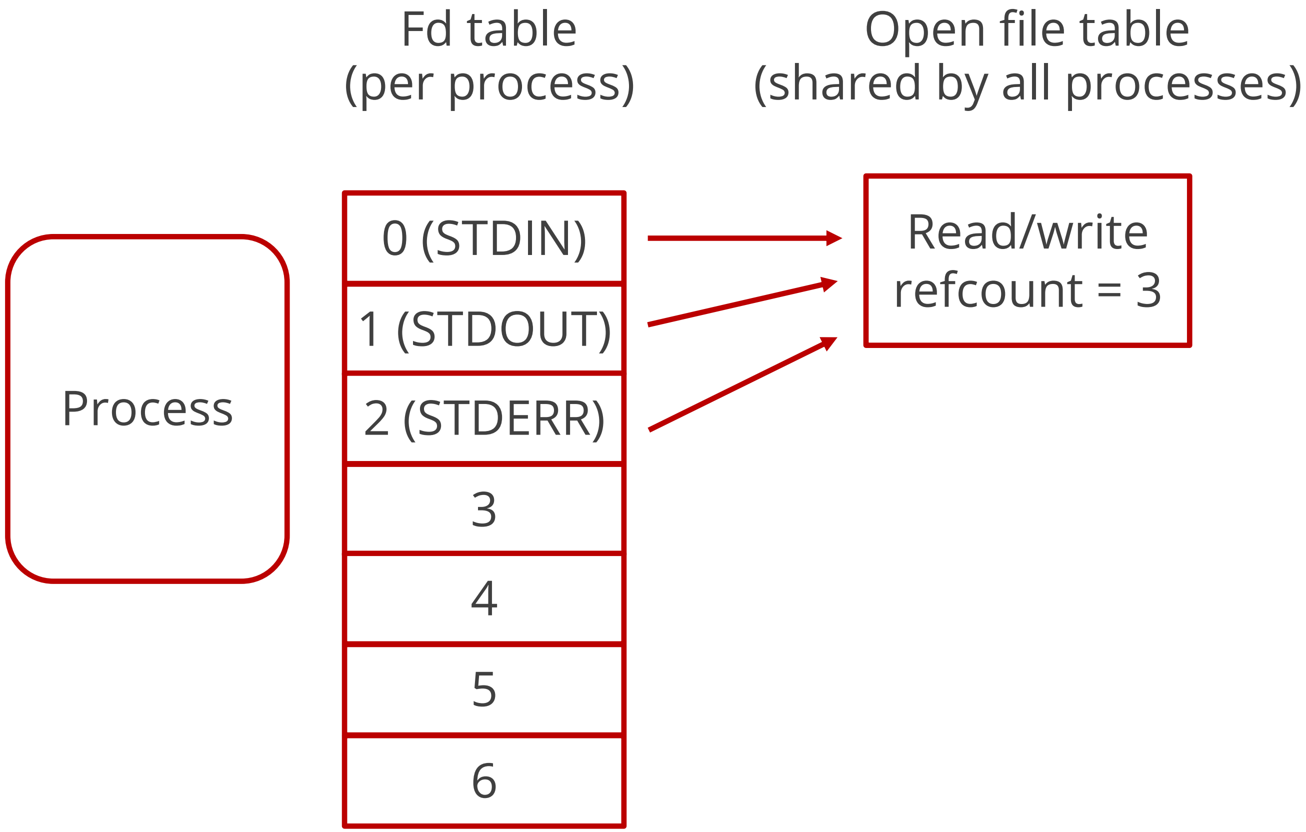
Solution: Open-file state

Add an `open` operation + “state”

“Open-file” structure (file descriptor) stores

- Filesystem / partition
- Filesystem-relative file number
- Operations allowed: eg read vs write
- Cursor position

Open files (UNIX model)



Fd table
(per process)

Open file table
(shared by all processes)

Process

0 (STDIN)

1 (STDOUT)

2 (STDERR)

3

4

5

6

Read/write
refcount = 3

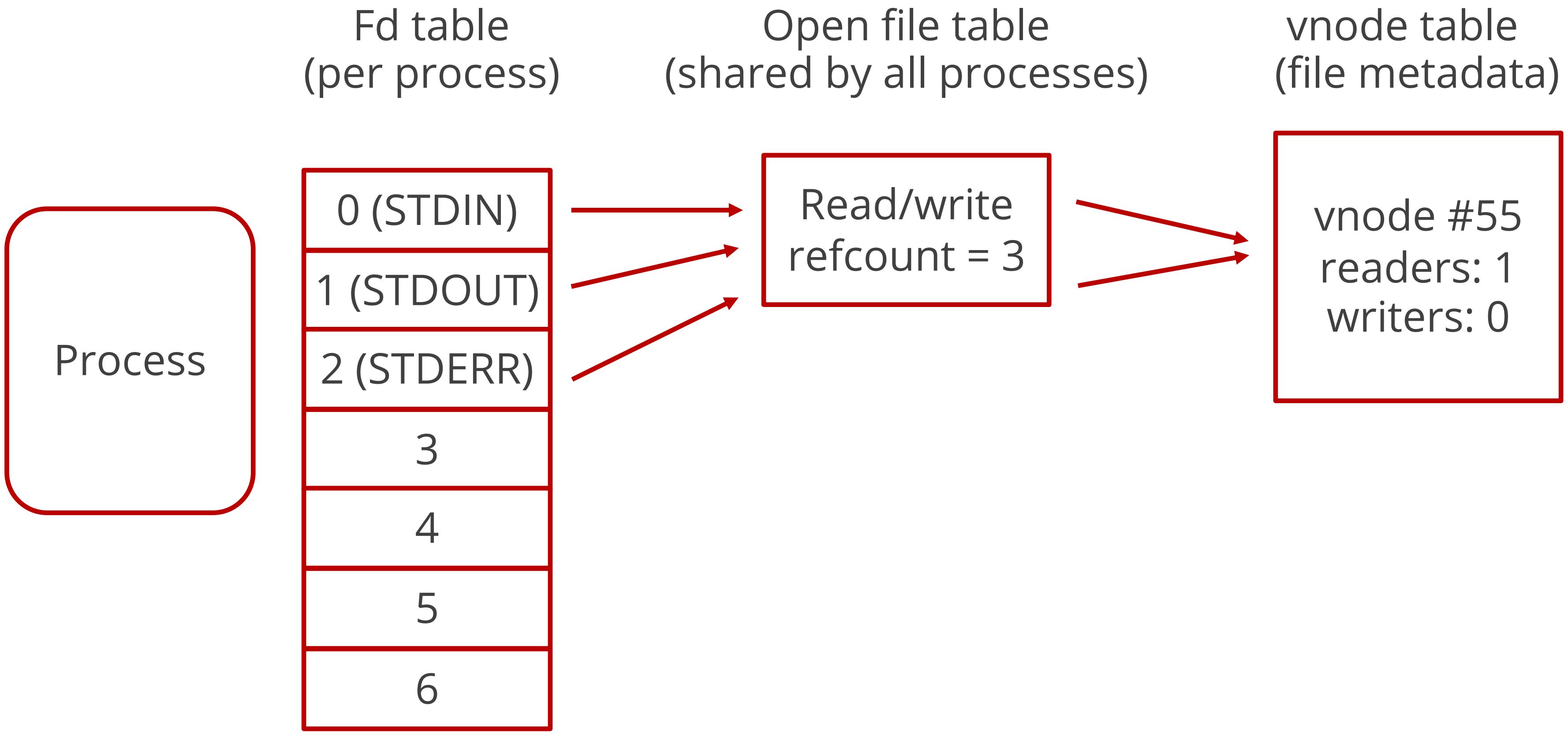
Open files (Unix model)

"In-core" file state - avoid going to disk repeatedly

- Mirror of on-disk structure (File number, size, permissions, modification time, …)
- Any other filesystem specific information

Shared when file is opened multiple times

Open files (UNIX model)



Fd table
(per process)

Open file table
(shared by all processes)

vnode table
(file metadata)

Process

0 (STDIN)
1 (STDOUT)
2 (STDERR)
3
4
5
6

Read/write
refcount = 3

vnode #55
readers: 1
writers: 0

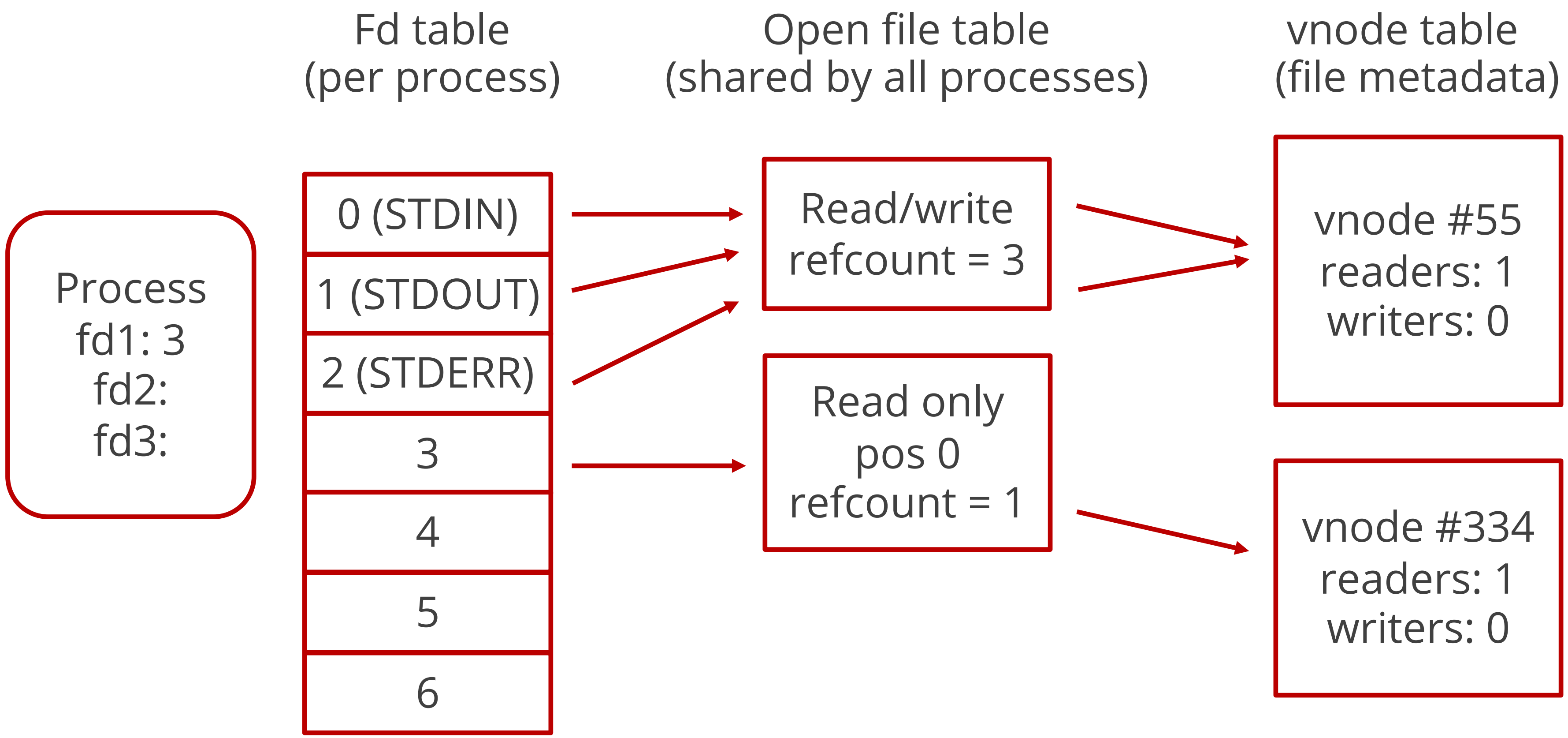
Open files - example

```
char buf[10];

int fd1 = open(“foo.c”, O_RDONLY, 0);
int fd2 = dup(fd1);
int fd3 = open(“foo.c”, O_RDONLY, 0);
```

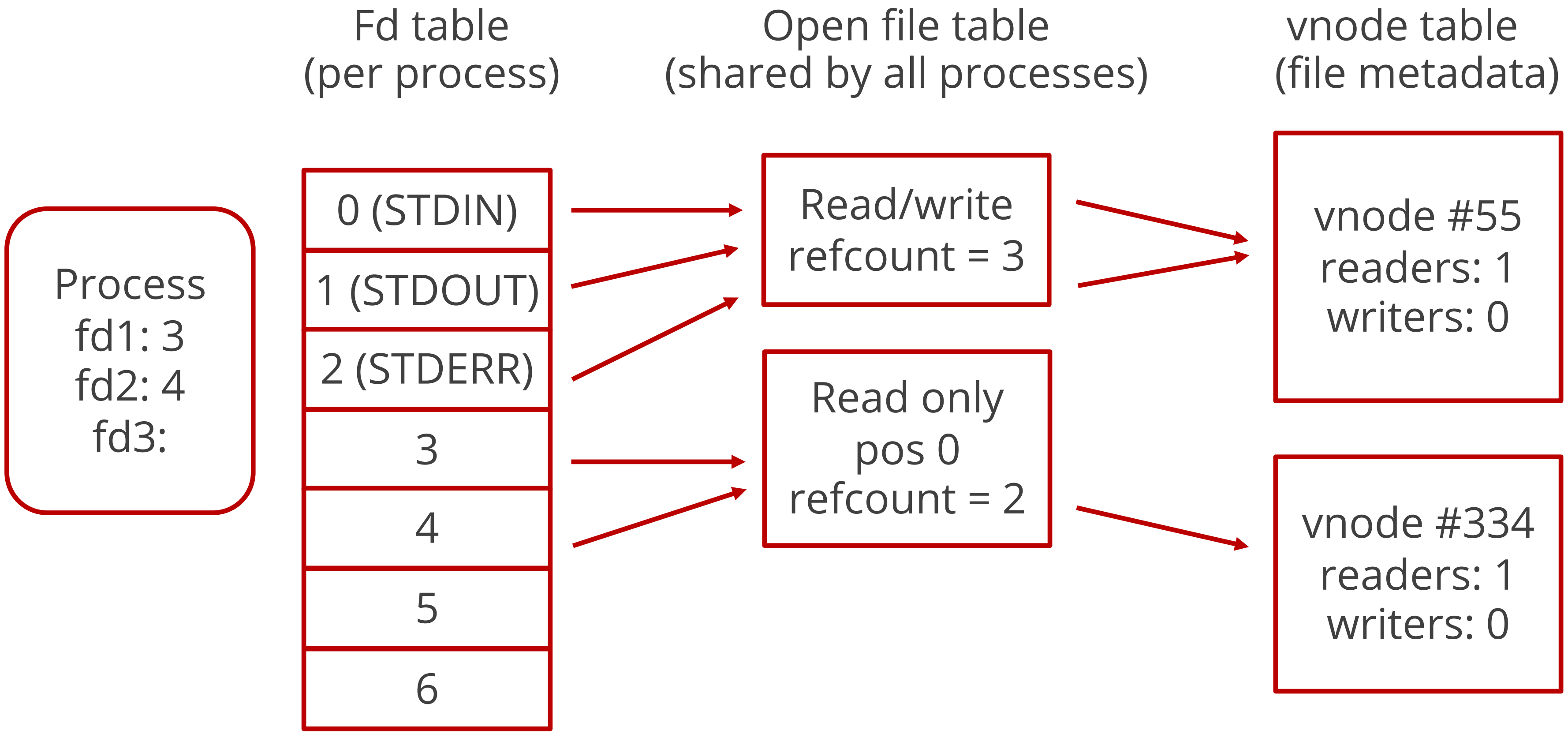
What’s wrong with this example code?

“Open File” vs “In-Core File”



```
int fd1 = open(“foo.c”, O_RDONLY, 0);
```

“Open File” vs “In-Core File”



Fd table
(per process)

Open file table
(shared by all processes)

vnode table
(file metadata)

Process
fd1: 3
fd2: 4
fd3:

0 (STDIN)
1 (STDOUT)
2 (STDERR)
3
4
5
6

Read/write
refcount = 3

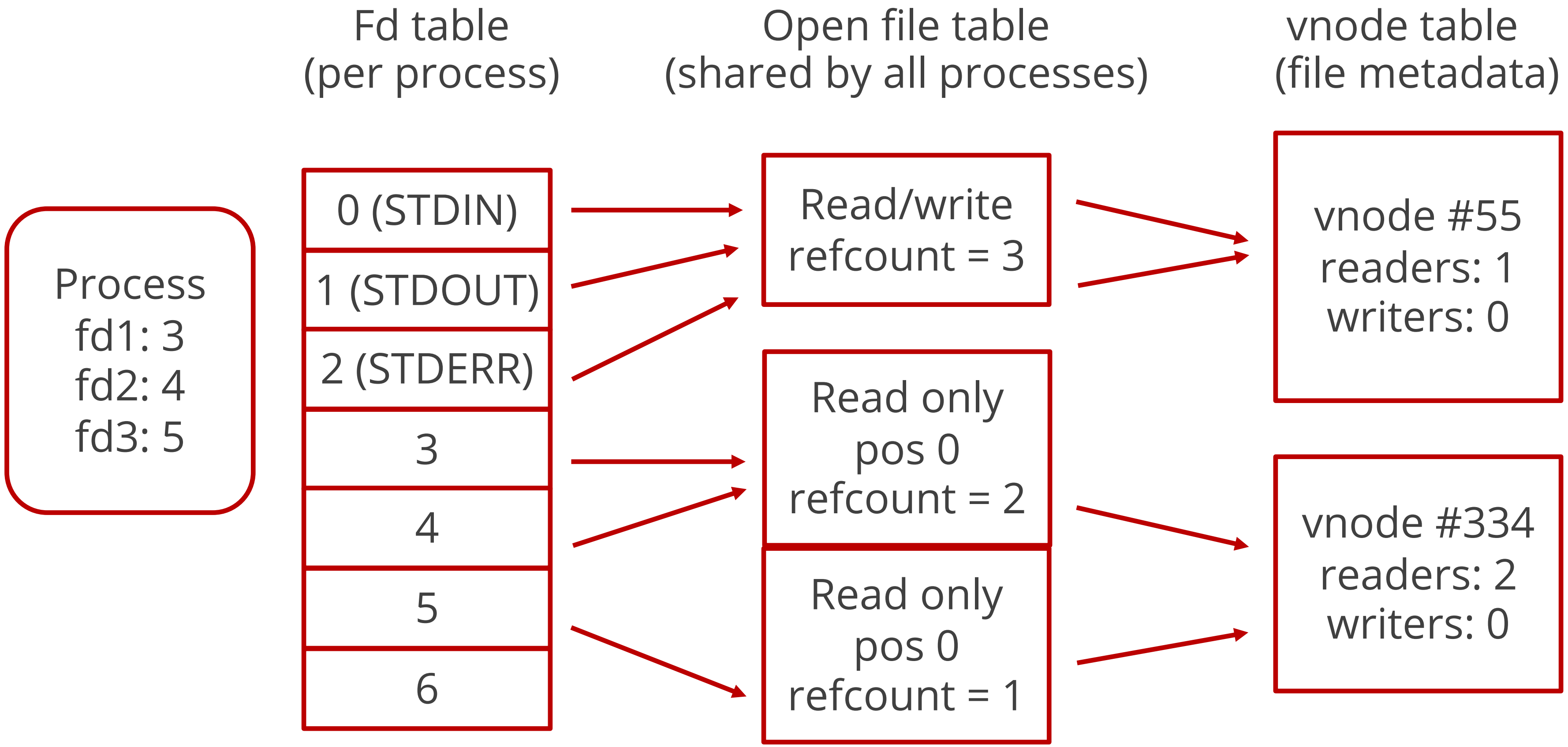
Read only
pos 0
refcount = 2

vnode #55
readers: 1
writers: 0

vnode #334
readers: 1
writers: 0

```
int fd2 = dup(fd1);
```

“Open File” vs “In-Core File”



Fd table
(per process)

Open file table
(shared by all processes)

vnode table
(file metadata)

Process
fd1: 3
fd2: 4
fd3: 5

0 (STDIN)
1 (STDOUT)
2 (STDERR)
3
4
5
6

Read/write
refcount = 3

Read only
pos 0
refcount = 2

Read only
pos 0
refcount = 1

vnode #55
readers: 1
writers: 0

vnode #334
readers: 2
writers: 0

```
int fd3 = open(“foo.c”, O_RDONLY, 0);
```

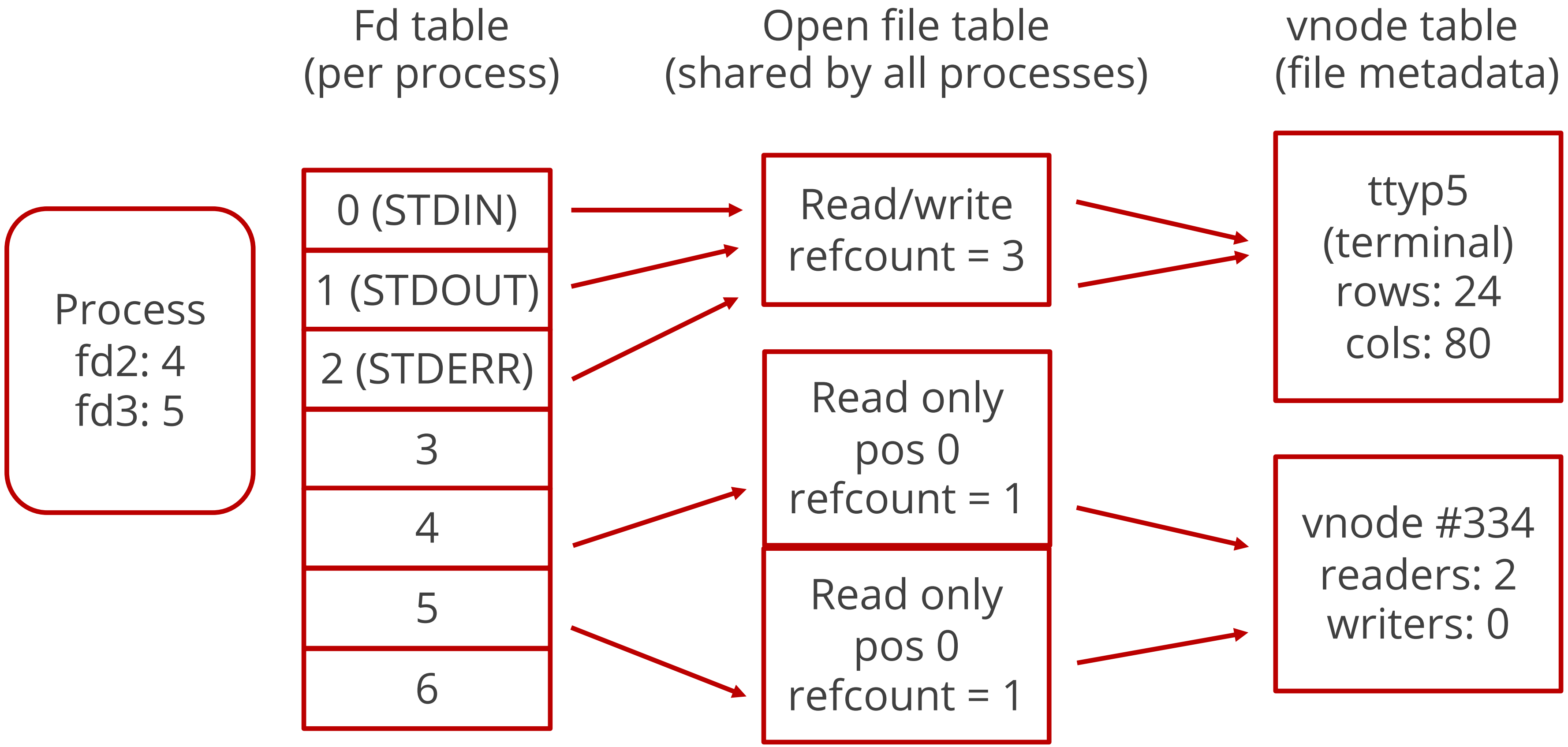
Open files - example

```
char buf[10];

int fd1 = open(“foo.c”, O_RDONLY, 0);
int fd2 = dup(fd1);
int fd3 = open(“foo.c, O_RDONLY, 0);
read(fd1, &buf, sizeof(buf));

off_t pos2 = lseek(fd2, 0, SEEK_CUR); /* ? */
off_t pos3 = lseek(fd3, 0, SEEK_CUR); /* ? */
```

“Open File” vs “In-Core File”



Fd table
(per process)

Open file table
(shared by all processes)

vnode table
(file metadata)

Process
fd2: 4
fd3: 5

0 (STDIN)
1 (STDOUT)
2 (STDERR)
3
4
5
6

Read/write
refcount = 3

Read only
pos 0
refcount = 1

Read only
pos 0
refcount = 1

ttyp5
(terminal)
rows: 24
cols: 80

vnode #334
readers: 2
writers: 0

```
close(fd1);
```

Let’s use file descriptors

printf writes to STDOUT. Add to this C code so the second printf writes to “error.txt” using `open` and `close`

```
printf("STDOUT is the command line\n”);




printf(“error.txt is STDOUT\n”);
```

Challenge: Are there any correctness or performance implications of how `open` works when multithreading?

What we’re covering today: Filesystem interface

What are files?

`open` and fds

Directories and ownership

Directory Types

Single-level

- Flat global namespace - only *one* test.c
- Ok for floppy disks (maybe)

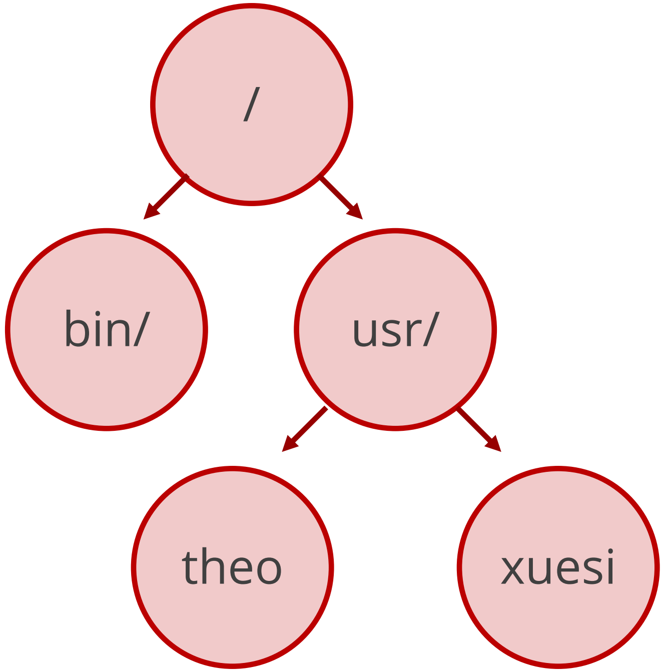
Two-level

- Every user has a directory
- One test.c *per user*
- Typical of early timesharing

Tree Directories

Directories are special files

- Created with special system calls - `mkdir`
- Format understood + maintained by OS



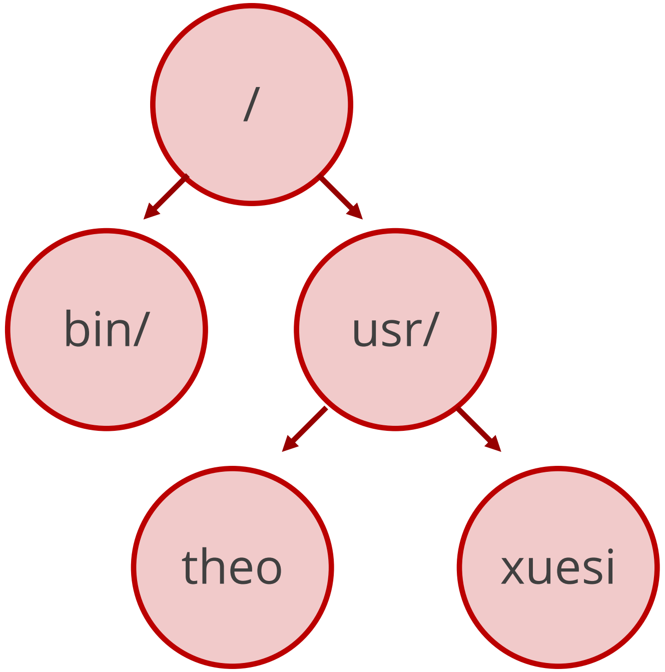
Tree Directories

Directories are special files

- Created with special system calls - `mkdir`
- Format understood + maintained by OS

Absolute Pathname

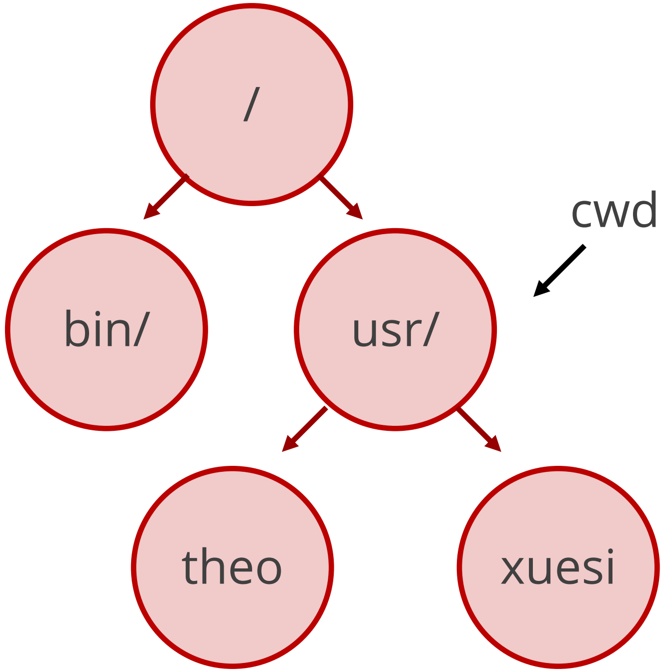
- Sequence of directory names
- Starting from “root”
- Ending with a file name
- `/usr/theo`



Tree Directories

Current directory (“.”, cwd)

- “Where I am now” (e.g. /usr/)
- Start of *relative* pathname
  - ./xuesi -> /usr/xuesi
  - ../bin -> /bin/
- Each process has a cwd



Tree Directories

Current directory (“.”, cwd)

- “Where I am now” (e.g. /usr/)
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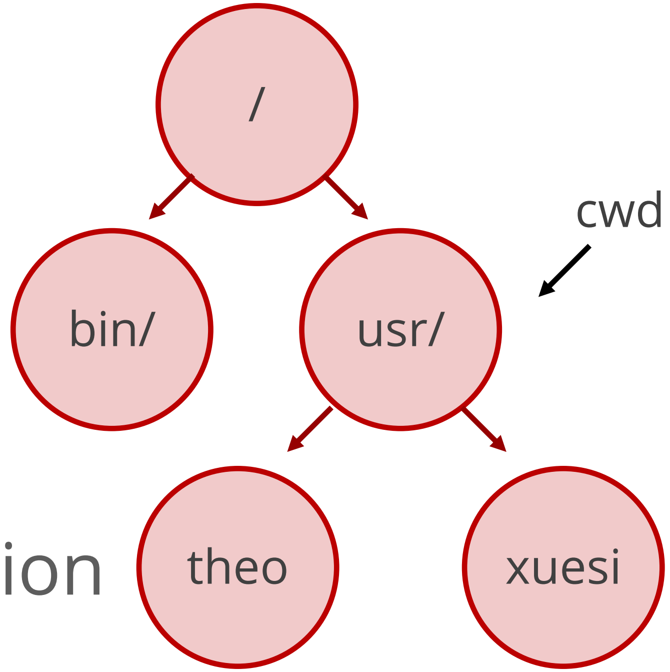
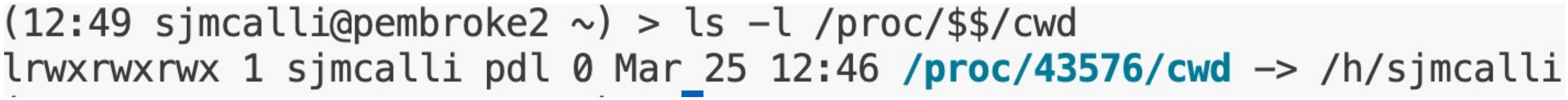


Almost everything is a file description



```
(12:49 sjmcalli@pembroke2 ~) > ls -l /proc/$$/cwd
lrwxrwxrwx 1 sjmcalli pdl 0 Mar 25 12:46 /proc/43576/cwd -> /h/sjmcalli
```

Protection - typical baseline

Files specifies *owner, group*

- Permissions for owner, permissions for group members
- Permissions for “other” / “world"

Traditional Unix encoding

- `chmod 777 example.txt`
- `r w x    r - x    - - x = 0751` (octal)
- `1 1 1    1 0 1    0 0 1`
- V7 Unix: 3 16-bit words specified all permission info
  - permission bits, user #, group #

What we’ve covered today: Filesystem interface

After the lecture today, you should be able to:

- Explain what a file is and operations that exist on files
- Discuss why we need an open syscall and file descriptors
- Compare different directory types

Next time: How do filesystems enable the file abstraction?