6.181: Filesystems (pt. 1)

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Why do we need filesystems?

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

What makes them interesting?

- Crash recovery
- Performance + concurrency
- Sharing + security
- Powerful abstractions (e.g., proc, afs, 9P, pipes, etc.)

xv6 FS software layers

0: System calls

1: Names + FDs

2: Inodes

3: Inode cache + Buffer cache

4: Log

5: Virtio disk driver

Focus for today

High-level design choices in system calls

- Objects: Use files (not virtual disks or databases)
- Content: Use byte arrays (not structured)
- Naming: Human-readable (not ID numbers)
- Organization: Name hierarchy
- Synchronization: None (no locking, no versions)
  - link() and unlink() can change names concurrently w/ open()

0: System call layer

```
fd = open(“x/y”, flags);     // creates a fd
write(fd, “abc”, 3);         // writes 3 bytes
link(“x/y”, “x/z”);          // creates a link
unlink(“x/y”);               // removes x/y
write(fd, “def”, 3);         // writes 3 more bytes
close(fd);                   // closes the fd
```

File x/z contains abcdef

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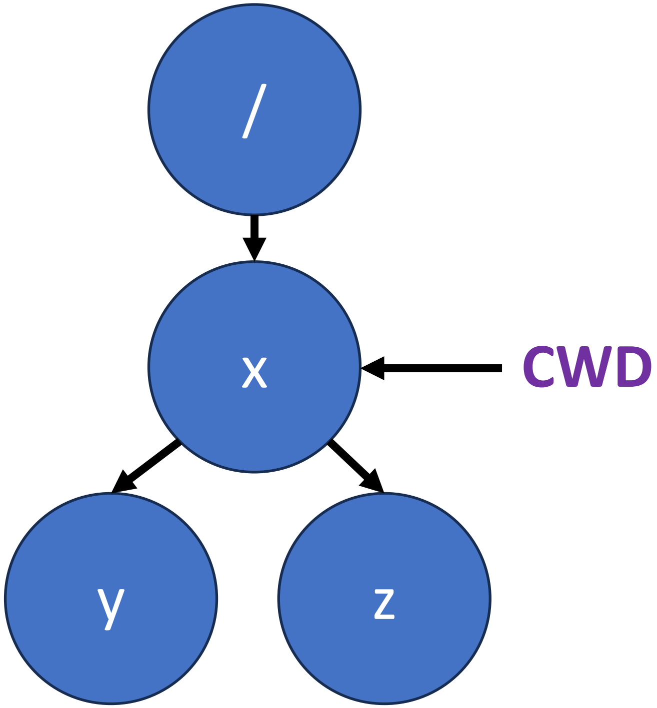
1: Name layer



- Path names are organized as a tree
- No cycles, but multiple names can refer to the same file (i.e., via link())
- Processes share the namespace
- But each process has a *current working directory* (CWD)
- Absolute path: /x/y
- Relative path: x/y

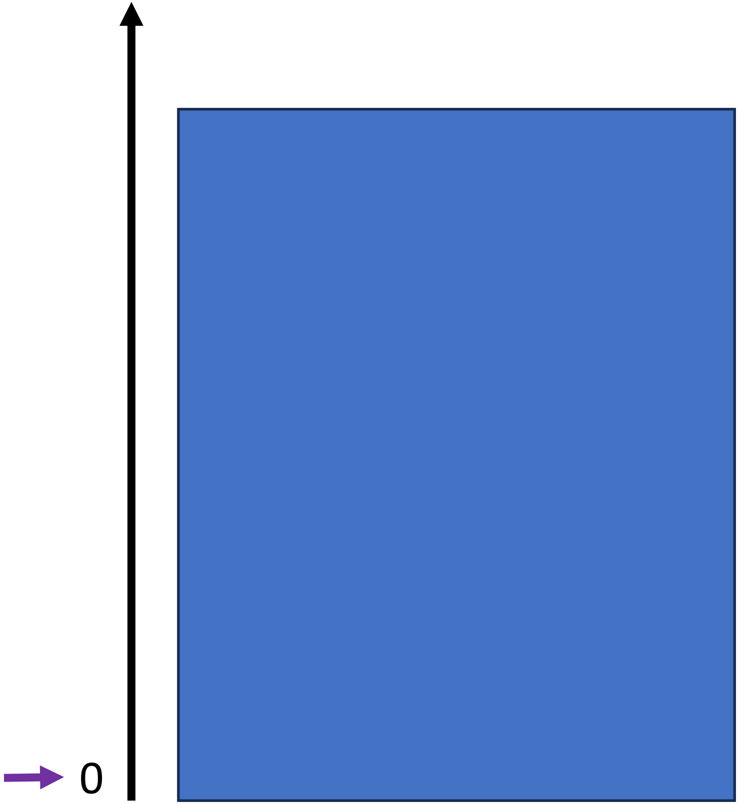
1: FD Layer

- Each process has its own FD number namespace

- Each FD identifies a file created by open()
  - By convention STDIN (0), STDOUT (1), STDERR (2)
  - Lowest available FD number is allocated during open()
  - Survives even if the file is unlinked (i.e., deleted)

- A file is an object that you can read and write to like a stream

Interacting with a file



- FDs access file as an array of bytes, very similar to an address space
- Each FD has a ”**cursor**” to the file

Interacting with a file

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Interacting with a file

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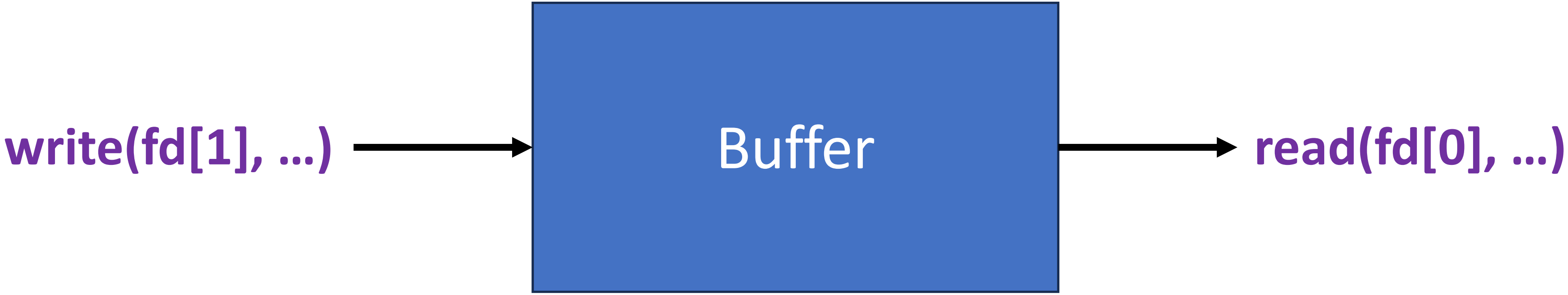
- Each FD has a ”**cursor**” to the file
- read() advances the cursor
- write() does too

Some files are special

- e.g., a pipe()
- Usage: int fds[2]; pipe(fds);



xv6 FS software layers

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Focus for today

2: Inode layer

- **Inode:** Records the details of a file
  - Tracks the size of the file and where on the disk the data is stored
  - Has a link count (and open FD count) to figure out when to free
  - Deallocation deferred until link + open count is zero

- **I-number:** Refers to an inode, similar to an FD
  - Uniquely identifies a position on disk

Where is data stored?

- On a *persistent* storage medium
  - Data doesn’t go away under loss of power
- Common storage mediums
  - **HDDs:** High capacity, slow, inexpensive
  - **SSDs:** Lower capacity, faster, more expensive
  - More choices on the horizon
- Disks accessed in fixed-sized units (like pages)
  - Called *sectors*, historically 512 bytes

Performance characteristics

- Applies to both HDDs and SSDs
- Sequential access much faster than random
- Big reads/writes much faster than small ones
- Both facts influence FS design

Disk blocks

- Typically, multiple sectors are combined to form *blocks*
  - e.g., a 4KB block is 8 sectors
- Needed to reduce book-keeping and seek overhead
- xv6 uses two sector blocks
- Every block has a block number
  - think of it like an address that identifies the location on the disk

xv6 FS software layers

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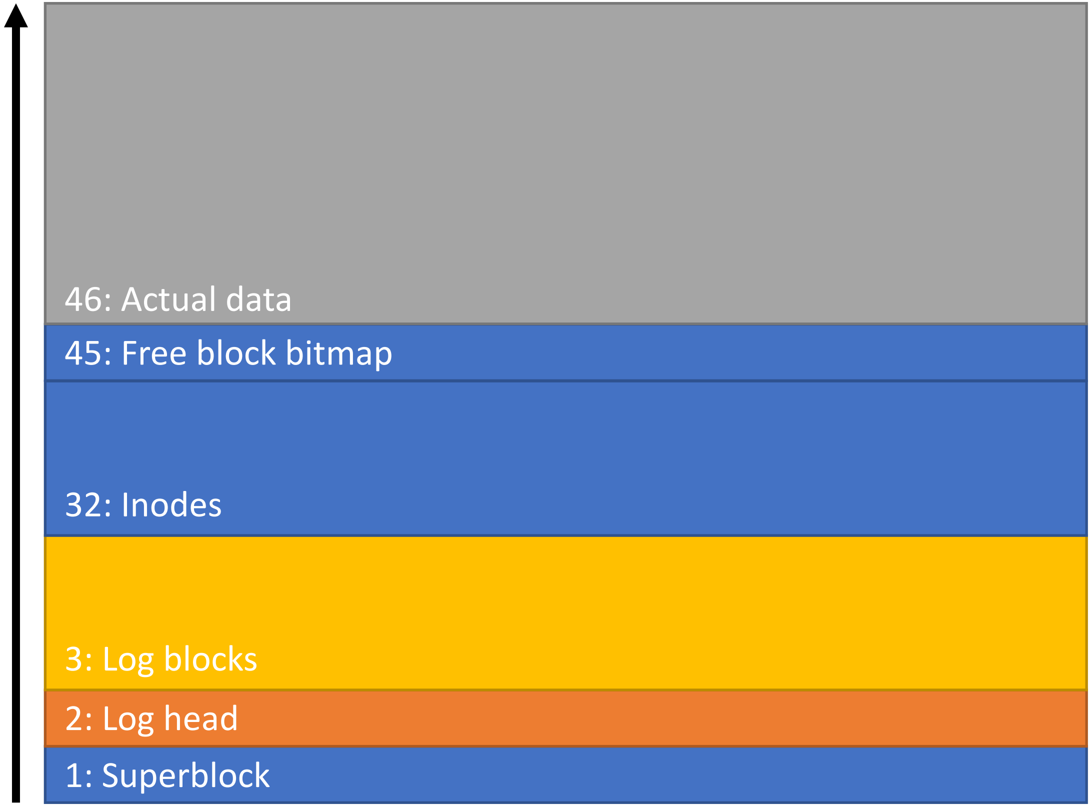
Focus for today

3: Inode + buffer cache

- Problem: Disk accesses are slow and random
- Idea: Store copies of inodes and blocks in RAM
- Works well because the same data is often accessed many times
- e.g., the same inodes and blocks are accessed each time a file is read
- No need to access the disk if a copy is available!

On-disk layout



xv6 provides mkfs program

- Generates this layout for a new (empty) FS
- The layout is static for the lifetime of the FS
- What is metadata?
  - Everything other than file content
  - Super block, inodes, bitmap, directory content

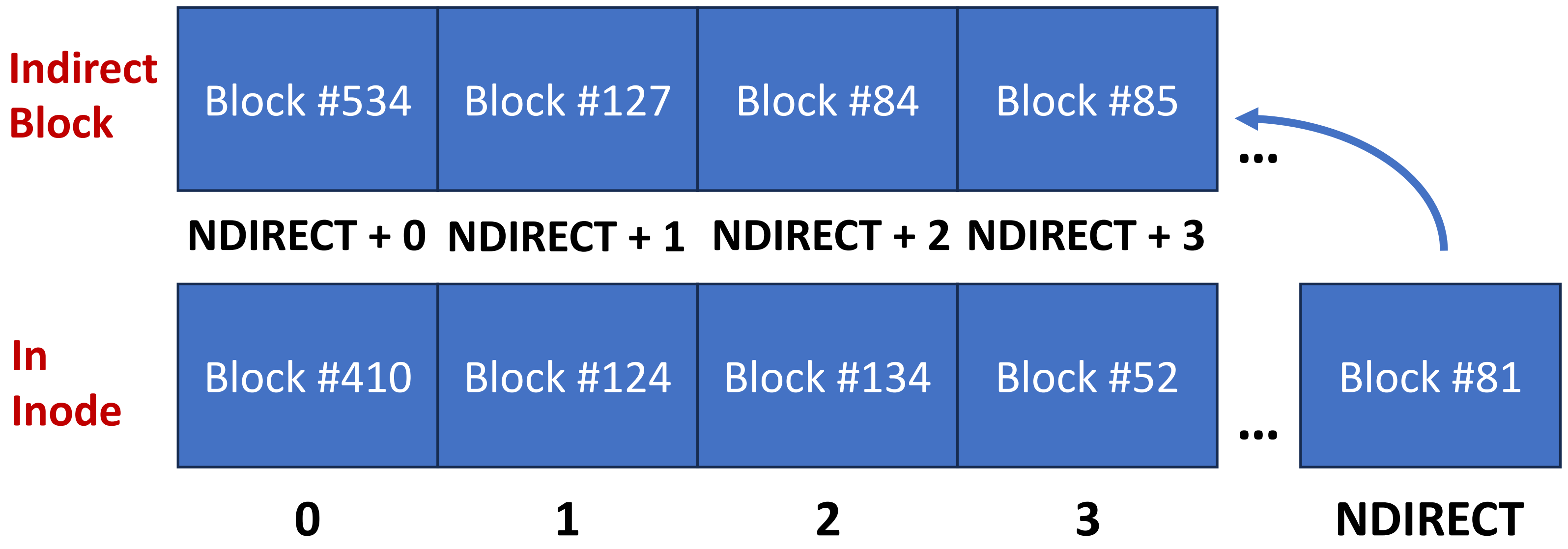
On-disk inode layout

- Type: Free, file, directory, or device
- Nlink: number of links
- Size: the size of the file in bytes
- Addrs: addresses of data blocks (array)
- Example: Find file's byte at 4000
  - 4000 / BSIZE (=1024) = 3; Look at 3rd addr entry

Block #410	Block #124	Block #124	Block #52	…
0	**1**	**2**	**3**	

Problem: Inode is fixed size!

- How can we fit large files into addrs?
- Idea: Use indirect block: a full block of more addrs



How to turn i-number to inode?

- i-number functions as an index to a disk block
- But have to skip log metadata
- Each inode is 64 bytes long
- Inode(i-number) = 32*BSIZE + 64*i-number

What about directories

- Represented much like a file
  - But users can not directly write contents
- Content is an array of dirents
- Each dirent:
  - i-number (of the file in the directory)
  - 14-byte file name
  - dirent is free (unused) if inum == 0

On-disk structure is tree-based

- Layer 1: Directory tree
- Layer 2: Inodes
- Layer 3: Blocks

Allocation pools: Inodes and Blocks

Example: Writing a file

Concurrency in FS

- xv6 has modest goals
  - Parallel read/write of different files
  - Parallel pathname lookup
- Disk also operates concurrently (e.g., intr)
- Even these pose interesting challenges

Conclusion

- File system maintains address space-like view of disk blocks
- Uses trees (like a page table) for naming and tracking disk blocks
- Next lecture: more details of xv6 and logging