# CS 423
# Operating System Design: Disks and Disk Scheduling

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Acks: Prof. Tianyin Xu and Prof. Adam Bates for slides

# Updates and Logistics

Midterm grades released!

Max: 39.5

Min: 10 (except who didn't submit)

Avg: 32.67

Median: 35

April 25th and 30th lectures - possibly on Zoom (will be recorded)

# THREE EASY PIECES

Three conceptual pieces

Make each application believe it has each resource to itself CPU and Memory

1. Virtualization

2. Concurrency

Provide mutual exclusion, ordering

3. Persistence

# MOTIVATION

What good is a computer without any I/O devices?

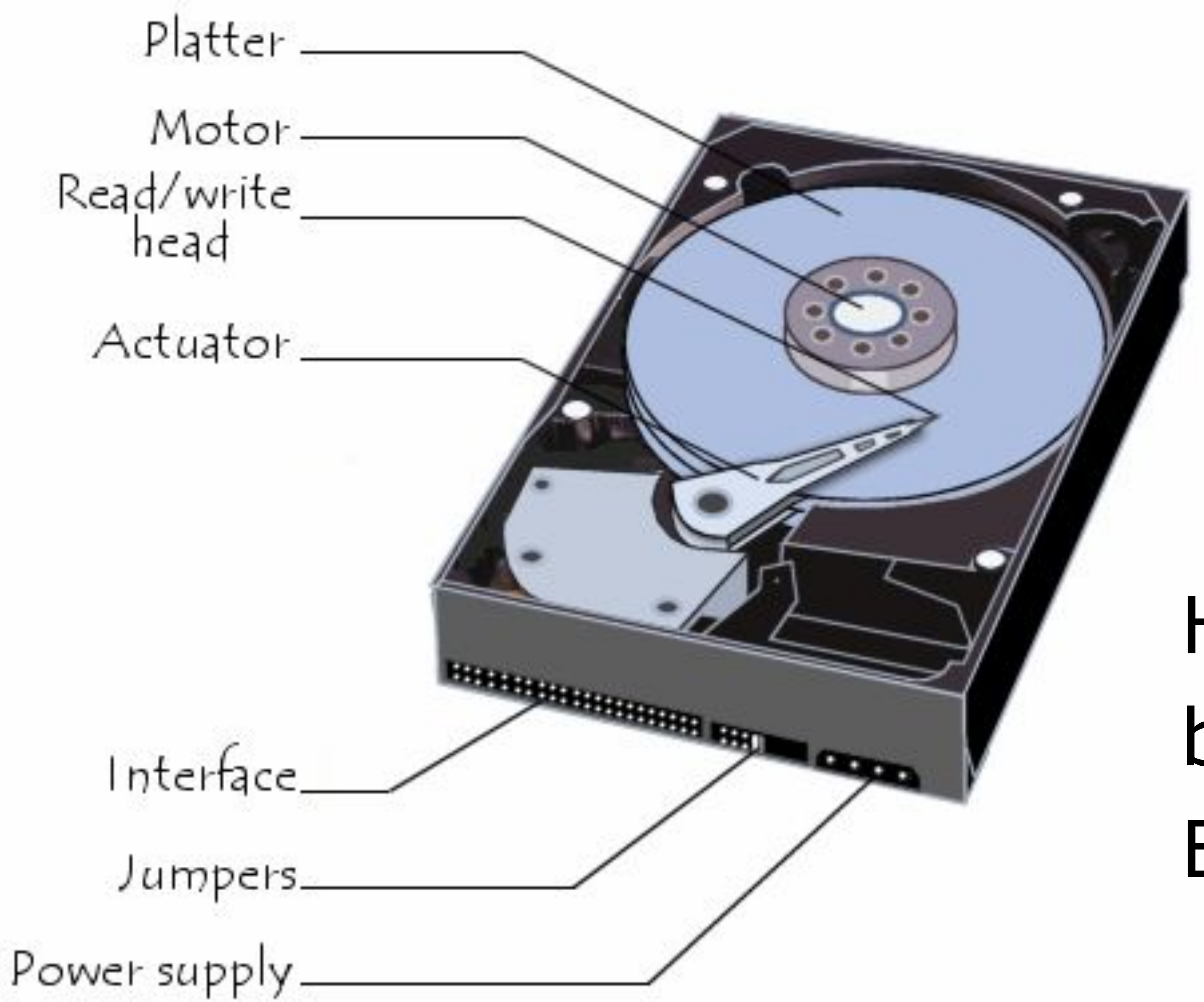
keyboard, display, disks

We will focus on disks…

# Questions

- What's the difference between contents in RAM vs. Disk?
- What is the granularity of access in RAM vs. Disk?
- How does the access pattern affect performance in RAM vs. Disk?

# Disk

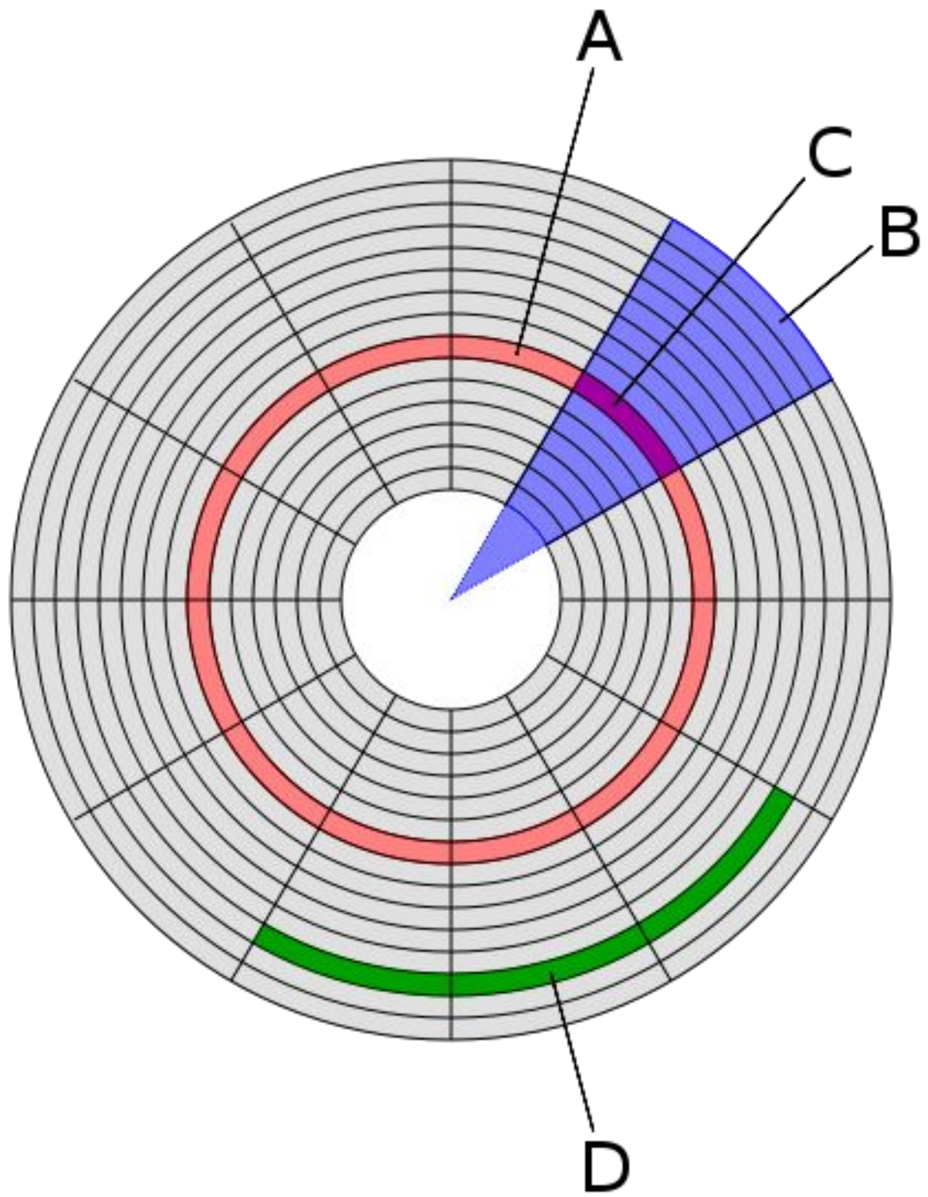



HDDs not SOTA by any means

But still relevant!

# Hard Disk Internals

A: Track.
B: Sector.
C: Sector of Track.
D: File

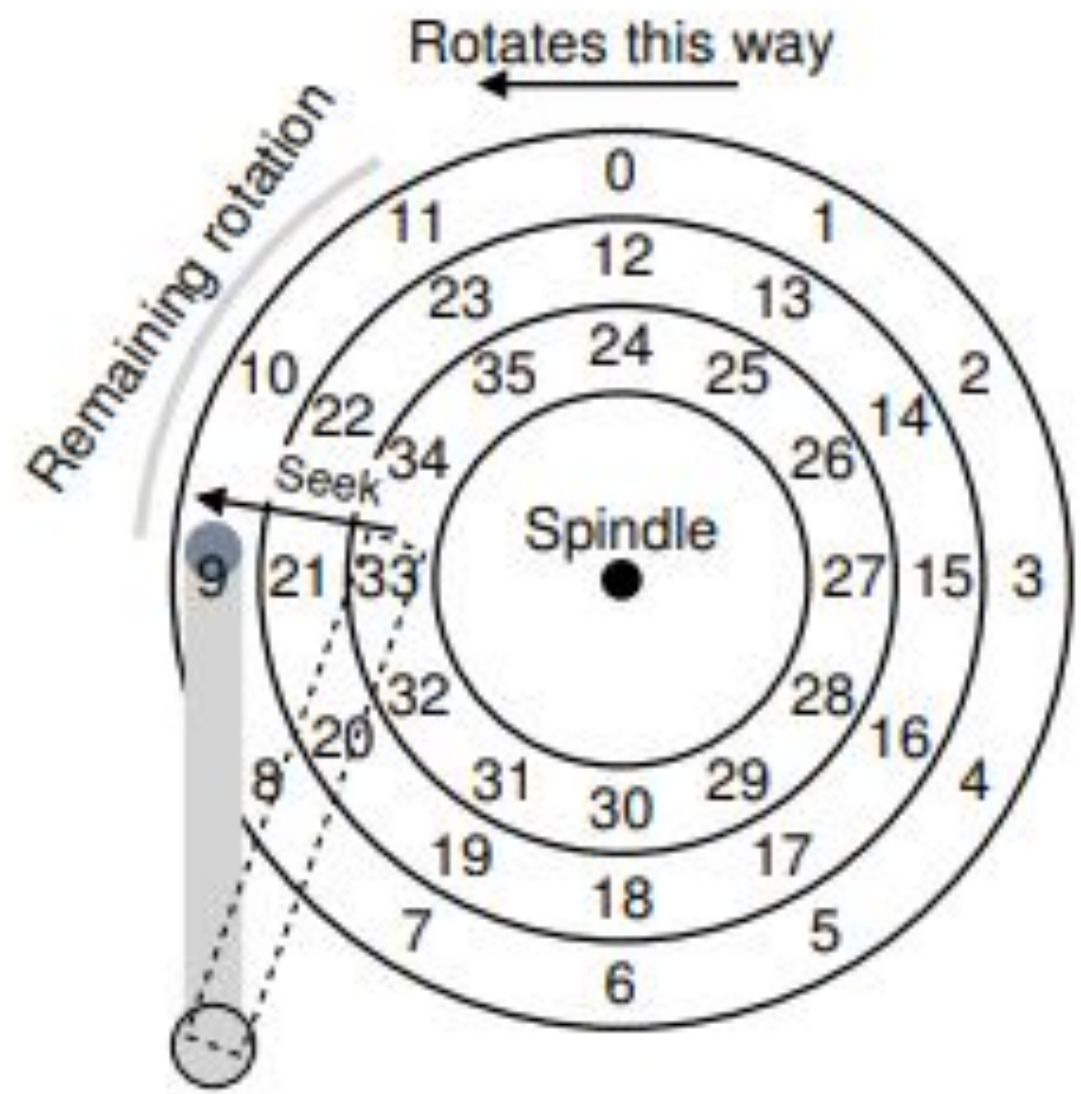


# Disk Internals

Seek: move head to the target track

Rotate: wait for target sector to be under head

Transfer: access data



# HDD in Action

https://www.youtube.com/watch?v=ojGvHDjHPb4

# Disk Access Time Example

- Disk Parameters
  - Advertised average seek time is 12 ms
  - Disk spins at 7200 RPM
  - Transfer rate is 125 MB/sec
- Assume idle disk (i.e., no queuing delay)

```
Disk Access Time=seek time +
           rotational delay +
             transfer time
```

# Disk Access Time Example

- Disk Parameters
  - Advertised average seek time is 12 ms
  - Disk spins at 7200 RPM
  - Transfer rate is 125 MB/sec
- Assume idle disk (i.e., no queuing delay)
- Q1: What is the total time to read 500 random sectors?
- Q2: What is the total time to read 500 sequential sectors (assume on same track)?

Discuss with your neighbors for 3 mins…

# Disk Access Time Example

- What is the total time to read 500 random sectors?

# Disk Access Time Example

- What is the total time to read 500 sequential sectors (assume on same track)?

# Bandwidth

Discuss for two mins…

Random bandwidth?

Sequential bandwidth?

# Disk Access Time Example

See the difference between random and sequential IO speeds on hard drives?

When have you noticed this difference?

   discuss for 1 min…

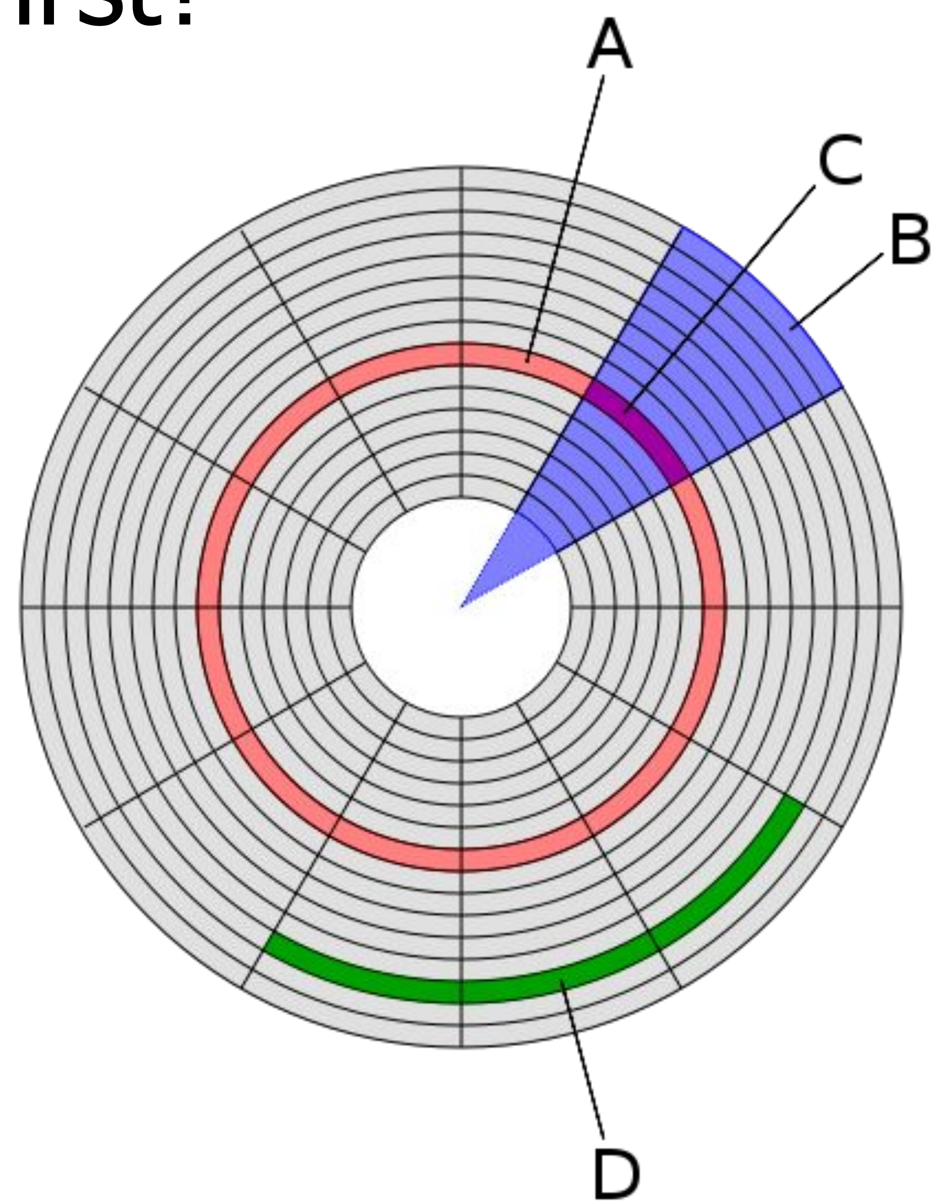
Always design for sequential IO on HDDs!

Random IO performance (slightly) better with SSDs

Why?

# Disk Scheduling

- Which disk request is serviced first?
  - FCFS
  - Shortest seek time first
  - SCAN (Elevator)
  - C-SCAN (Circular SCAN)

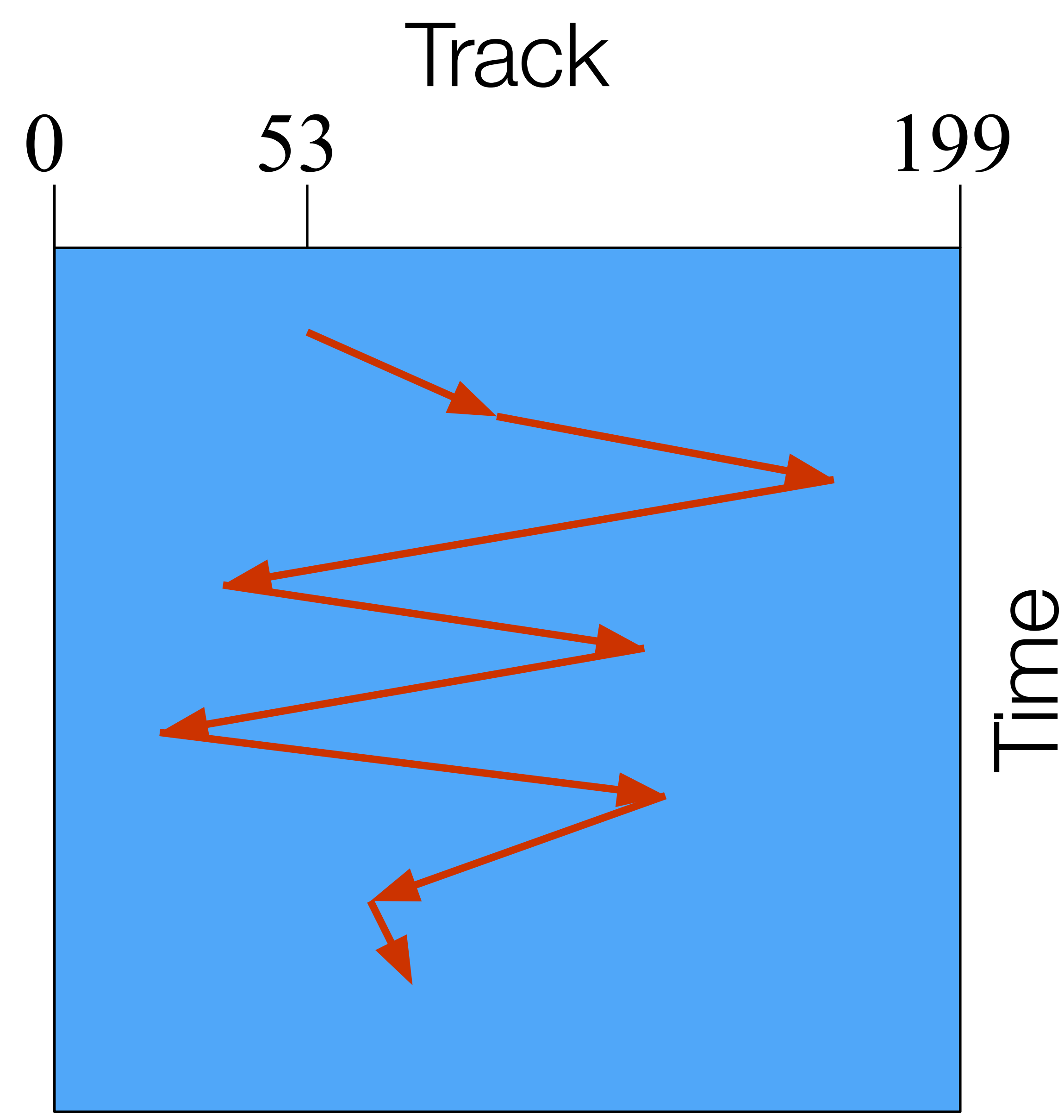



A: Track.
B: Sector.
C: Sector of Track.
D: File

**Disk Scheduling Decision** — Given a series of access requests, on which track should the disk arm be placed next to maximize fairness, throughput, etc?

# FIFO (FCFS) Order

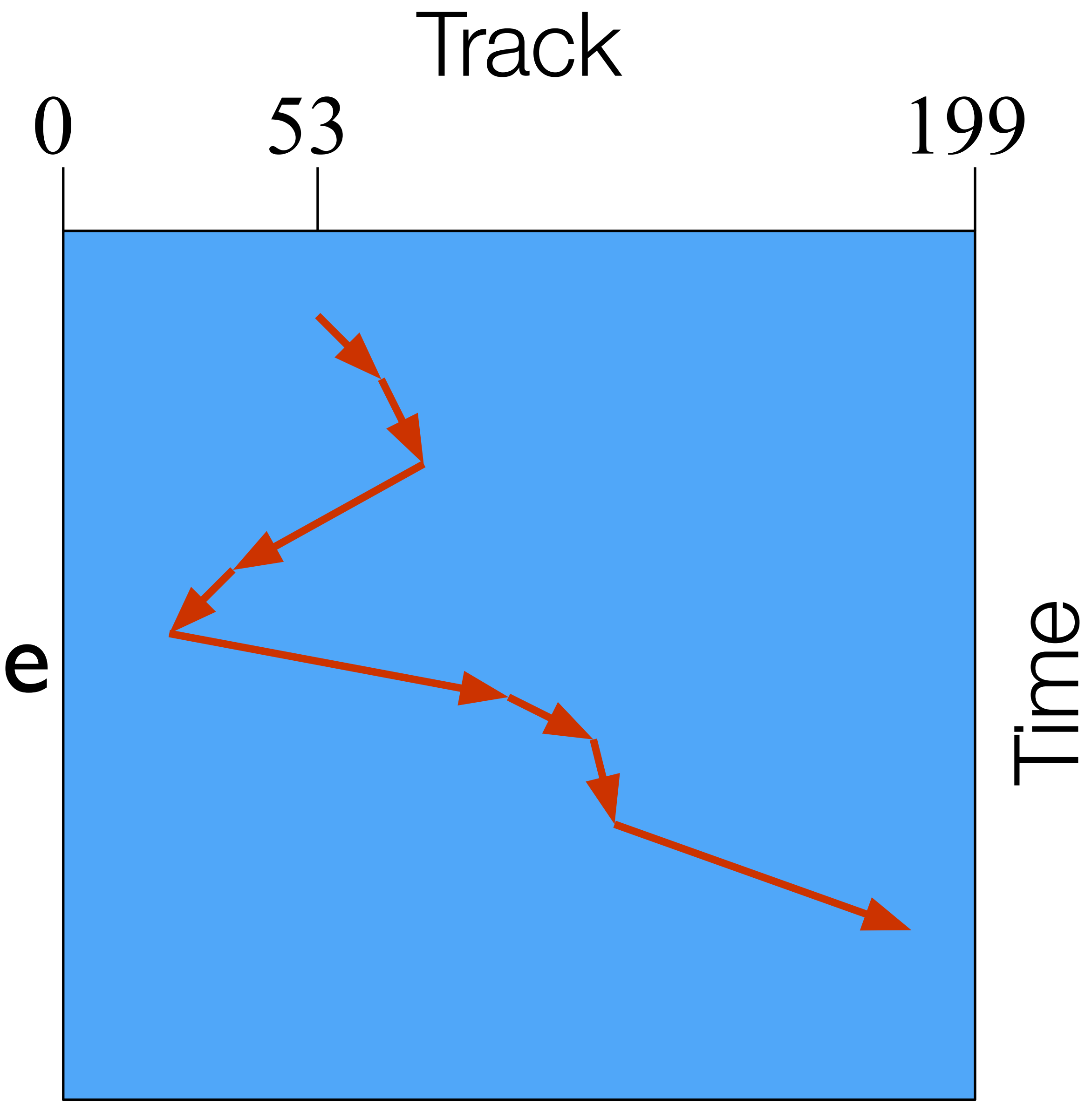
- Method
  - First come first serve
- Pros?
  - Fairness among requests
  - In the order applications expect
- Cons?
  - Arrival may be on random spots on the disk (long seeks)
  - When is it particularly bad?




98, 183, 37, 122, 14, 124, 65, 67

# SSTF (Shortest Seek Time First)

- Method
  - Pick the one closest on disk (greedy approach)
- Pros?
  - Tries to minimize seek time
- Cons?
  - ???

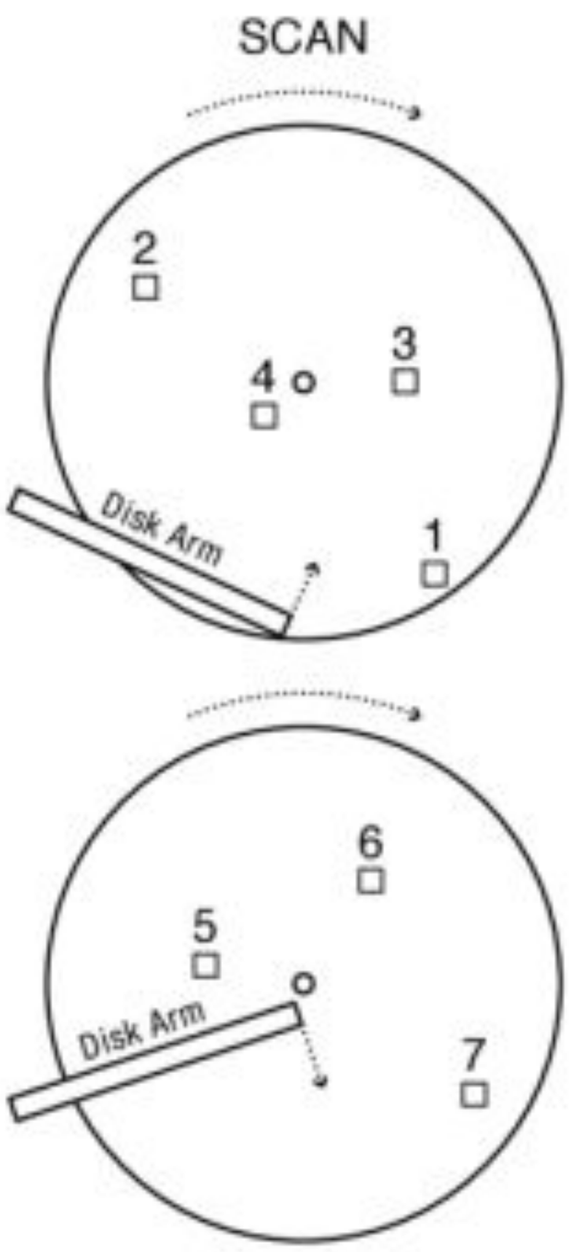



98, 183, 37, 122, 14, 124, 65, 67
(65, 67, 37, 14, 98, 122, 124, 183)

# SCAN (Elevator)

- Move outer to inner – service all requests along the way
- Move inner to outer – service all along the way

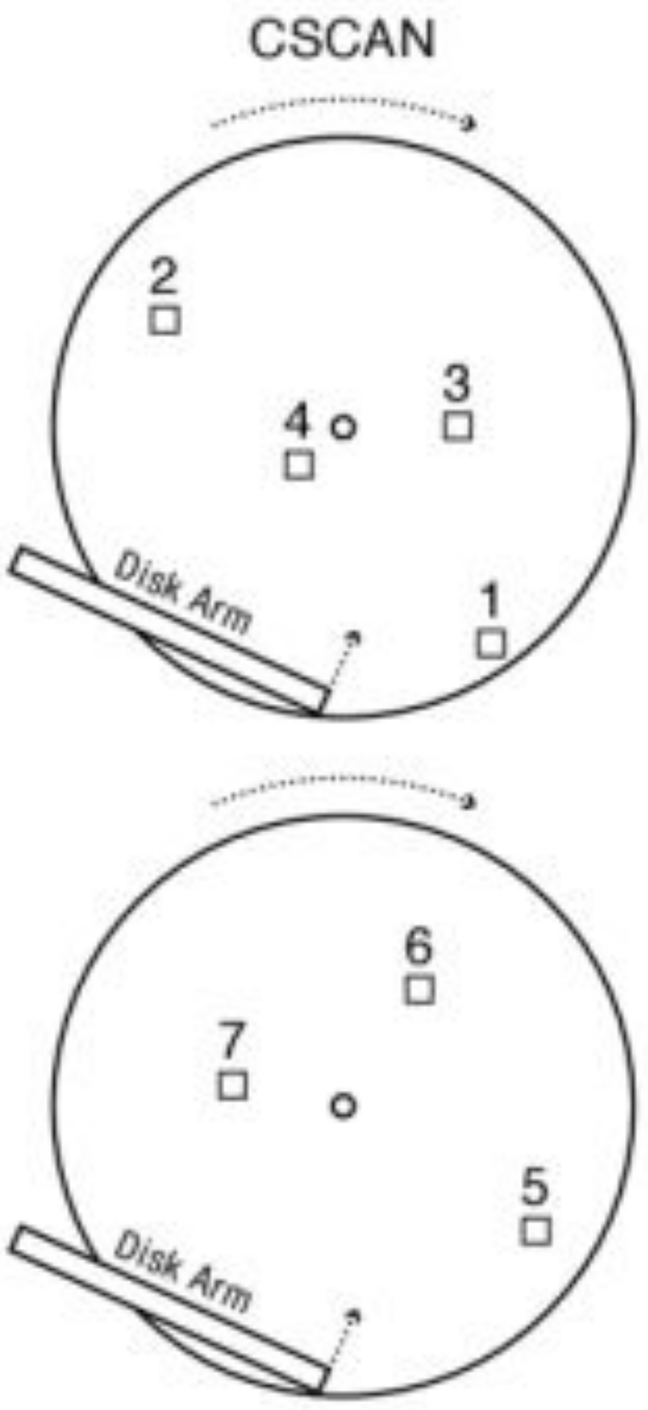
- Adv compared to SSTF:
  - Bounded time for each request



# C-SCAN (Circular SCAN)

Like SCAN
But, wrap around (i.e., only one direction)

- Adv over SCAN
  - By seeking to opposite side, moves head to where pending requests are likely to be denser
  - More fair
- Cons
  - Do nothing on the return (i.e., higher overhead)



# Scheduling Algorithms

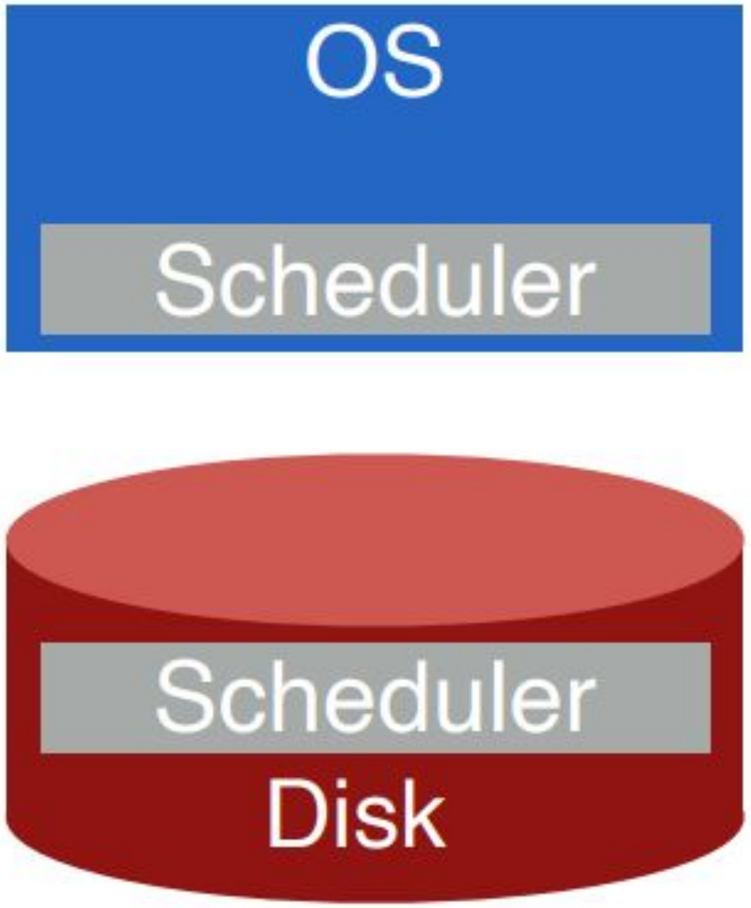
| *Algorithm Name* | Description |
|---|---|
| FCFS | First-come first-served |
| SSTF | Shortest seek time first; process the request that reduces next seek time |
| SCAN (aka Elevator) | Move head from end to end (has a current direction) |
| C-SCAN | Only service requests in one direction (circular SCAN) |
| LOOK | Similar to SCAN, but do not go all the way to the end of the disk. |
| C-LOOK | Circular LOOK.<br>Similar to C-SCAN, but do not go all the way to the end of the disk. |

# Who does Scheduling?

The OS?

The disk itself?

Both?



# Linux I/O Schedulers

- What disk (I/O) schedulers are available in Linux?

```
$ cat /sys/block/sda/queue/scheduler
noop deadline [cfq]
```

- As of Linux 2.6.10, it is possible to change the IO scheduler for a given block device on the fly!
- How to enable a specific scheduler?

```
$ echo SCHEDNAME > /sys/block/DEV/queue/scheduler
```

  - SCHEDNAME = Desired I/O scheduler
  - DEV = device name (e.g., sda)

# Linux NOOP Scheduler

- Insert all incoming I/O requests into a simple FIFO
- Merges duplicate requests
- When would this be useful?

# Linux NOOP Scheduler

- Insert all incoming I/O requests into a simple FIFO
- Merges duplicate requests (results can be cached)
- When would this be useful?
  - Solid State Drives! Avoids scheduling overhead
  - Scheduling is handled at a lower layer of the I/O stack (e.g., Disk firmware, RAID Controller, Network-Attached)
  - Host doesn't actually know details of sector positions

# Linux Deadline Scheduler

- Imposes a deadline on all I/O operations to prevent starvation of requests
- Maintains 4 queues:
  - 2 Sorted Queues (R, W), order by Sector
  - 2 Deadline Queues (R, W), order by Exp Time
- Scheduling Decision:
  - Check if 1st request in deadline queue has expired.
  - Otherwise, serve request(s) from Sorted Queue.
  - Prioritizes reads (DL=500ms) over writes (DL=5s) .Why?

# Linux CFQ Scheduler

- CFQ = Completely Fair Queueing!
- Maintain per-process queues.
- Allocate time slices for each queue to access the disk
- I/O Priority dictates time slice, # requests per queue
- Asynchronous requests handled separately — batched together in priority queues

# What Happens?

Assume 2 processes each calling read() with C-SCAN

```
void reader(int fd) {
char buf[1024]; int rv;
while((rv = read(fd, buf)) != 0)  {
assert(rv);
// takes short time, e.g., 1ms
process(buf, rv);
}
}
```

# What Happens?

Assume 2 processes each calling read() with C-SCAN

```
void reader(int fd) {
char buf[1024]; int rv;
while((rv = read(fd, buf)) != 0)  {
assert(rv);
// takes short time, e.g., 1ms
process(buf, rv);
}
}
```

P1: read 100, 101

P2: read 900, 901

After 1 ms

P1: read 102, 103

P2: read 902, 903

# Work Conservation

Work conserving schedulers always try to do work if there's work to be done

Sometimes, it's **better to wait** instead if system anticipates another request will arrive

Possible improvements from I/O merging

# Linux Anticipatory Scheduler

- Deceptive Idleness: A process appears to be finished reading from disk, but is actually processing data. Another (nearby) request is coming soon!
- Bad for synchronous read workloads because seek time is increased.
- Anticipatory Scheduling: Idle for a few milliseconds after a read operation in *anticipation* of another close-by read request.

# Summary

Disks: specific geometry with platters, spindle, tracks, sector, head, etc

DAT = seek time + rotation delay + transfer time

Sequential bandwidth is much higher than random bandwidth

Scheduling approaches: FCFS, SSTF, SCAN, C-SCAN

Schedulers are at multiple layers of the stack

Need to think together (e.g., Linux NOOP)

# What is above?

- Above the disk and IO scheduler? **The file system**!

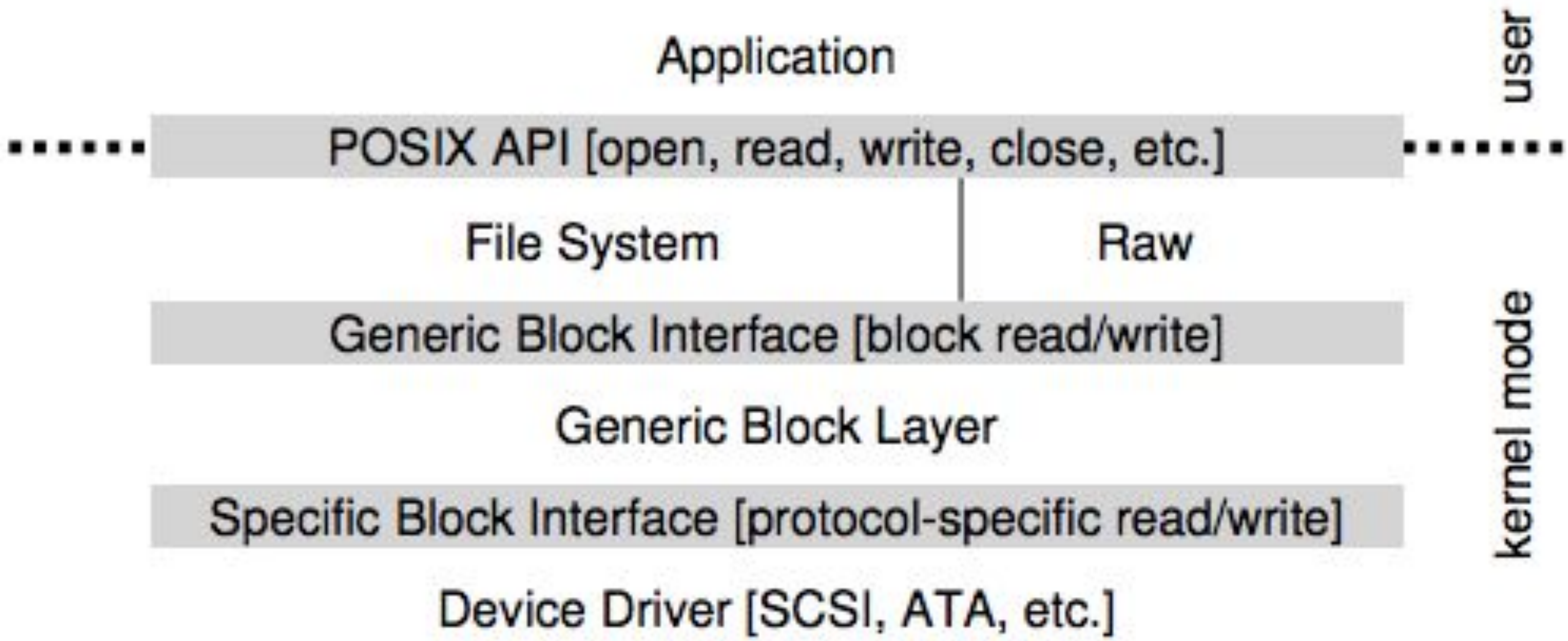
Abstracts many of the underlying details to higher-level applications

1. Presents data as named files– neat, clean abstraction: need not work with sector #s

2. Can be byte-oriented instead of blocks/sectors

3. Offer protection and sharing among users

4. Ensures data reliability



Application
user
POSIX API [open, read, write, close, etc.]
File System
Raw
Generic Block Interface [block read/write]
Generic Block Layer
Specific Block Interface [protocol-specific read/write]
Device Driver [SCSI, ATA, etc.]
kernel mode

# View of Disk

How does the FS view the disk?

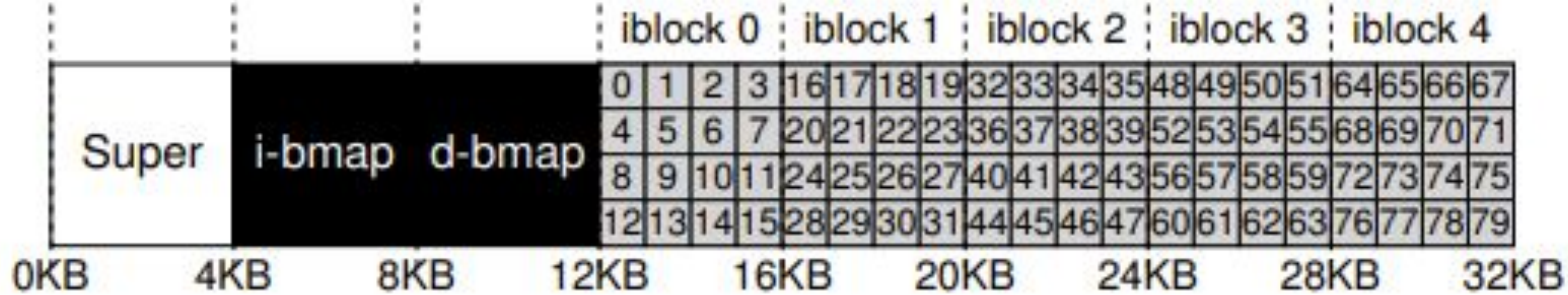
A linear block array! – the block device

It often doesn't need to understand the disk details (e.g., positions of sectors)

```
nvme0n1     259:0    0 953.9G  0 disk
├─nvme0n1p1 259:1    0   260M  0 part /boot/efi
├─nvme0n1p2 259:2    0    16M  0 part
├─nvme0n1p3 259:3    0 494.2G  0 part
├─nvme0n1p4 259:4    0  1000M  0 part
└─nvme0n1p5 259:5    0 458.4G  0 part /
```

# Disk Layout for a FS

Disk layout in a typical file system:




- Data Structures:
  - File data blocks: File contents (not shown)
  - Inodes: low-level file number
  - Directories: File names pointing to inodes
  - Bitmaps: track which disk blocks are free
    - Data bitmap (d-bmap)
    - Inode bitmap (i-bmap)