PERSISTENCE: I/O DEVICES

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CS 537, Spring 2023

ADMINISTRIVIA

Project 4: Grades today (hopefully?)

Project 5: How is it going? → Group

Midterm 2 → Canvas

Venue : Social Sciences 6210

Time : 5.45pm - 7:15 pm

Practice exams: Check Canvas (Files → Old Exams)

I'll post links on Canvas

Playlist → Concurrency

AGENDA / LEARNING OUTCOMES

How does the OS interact with I/O devices?

What are the components of a hard disk drive?

RECAP

OPERATING SYSTEMS: 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 → Input, Output to a process → what does OS do?

MOTIVATION

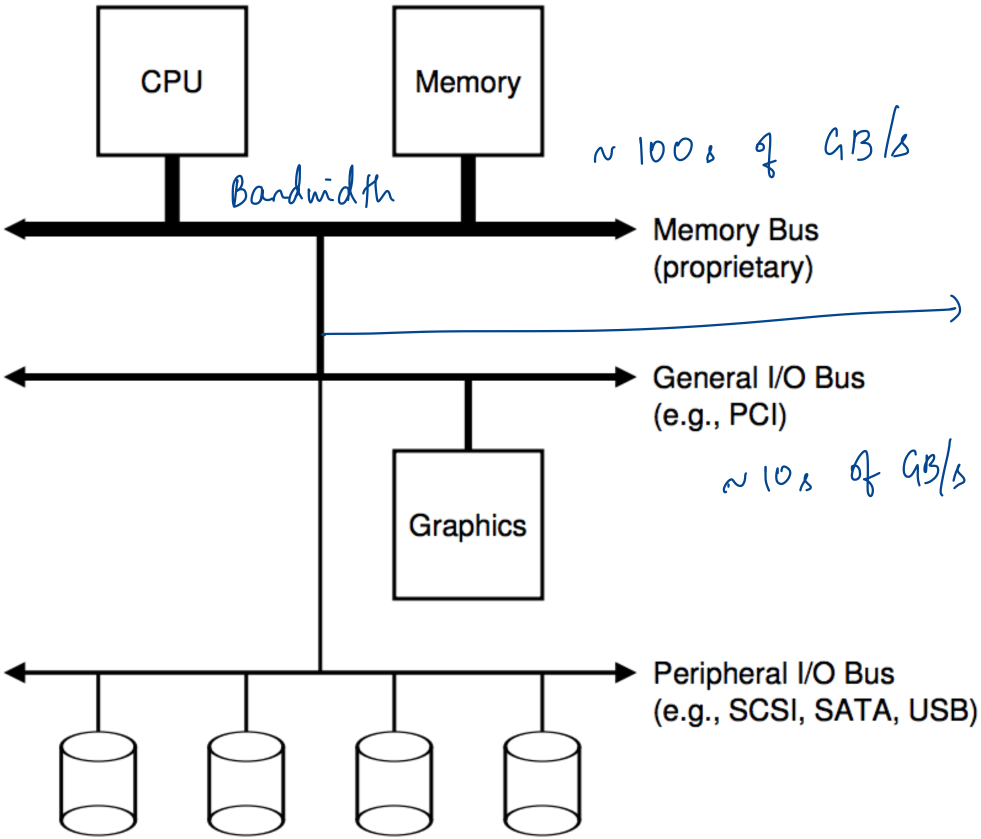
What good is a computer without any I/O devices?

keyboard, display, disks

We want:

- **H/W** that will let us plug in different devices
- **OS** that can interact with different combinations

HARDWARE SUPPORT FOR I/O



Bandwidth

~ 100s of GB/s

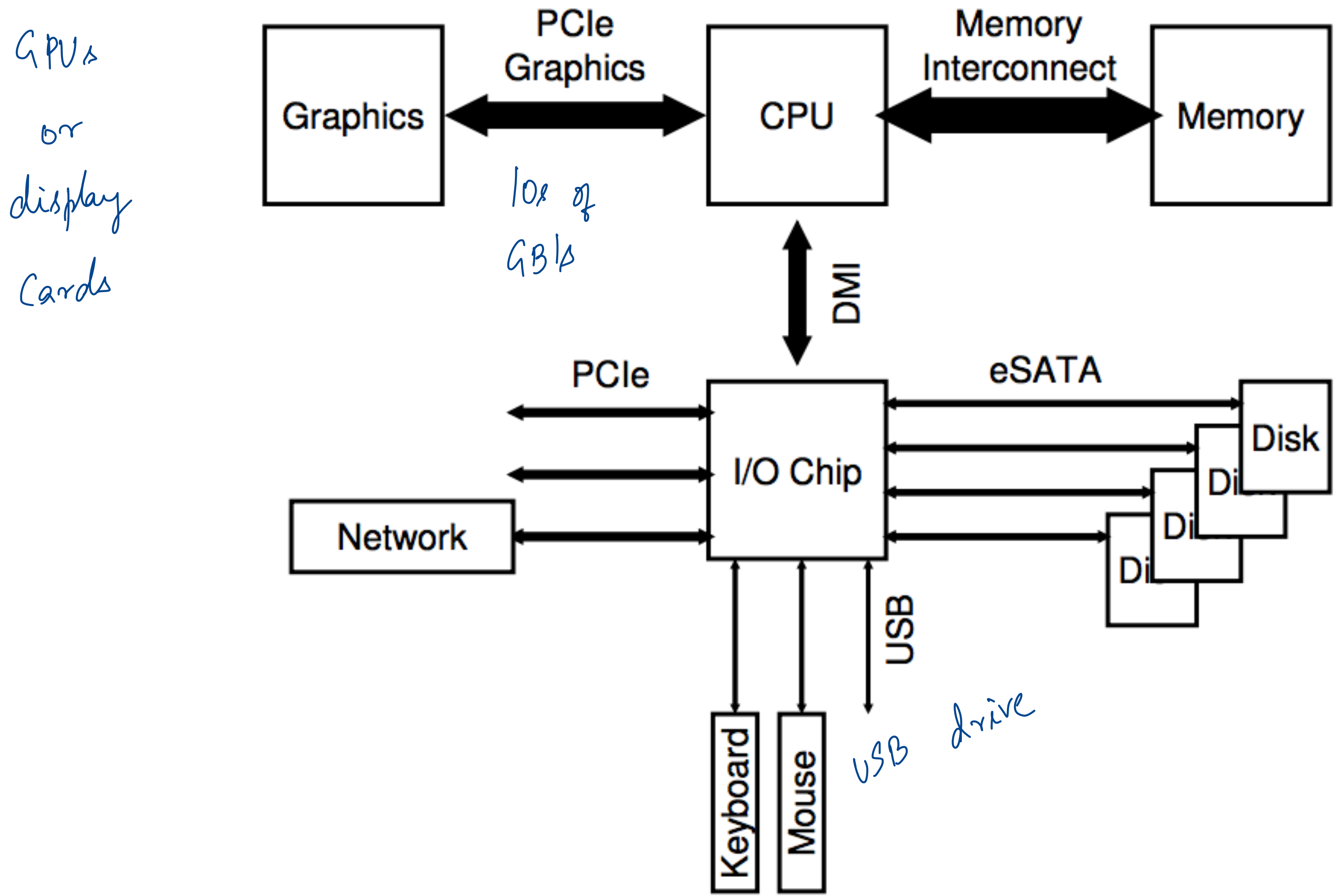
Bus → Link

~ 10s of GB/s

100 - 500 MB/s

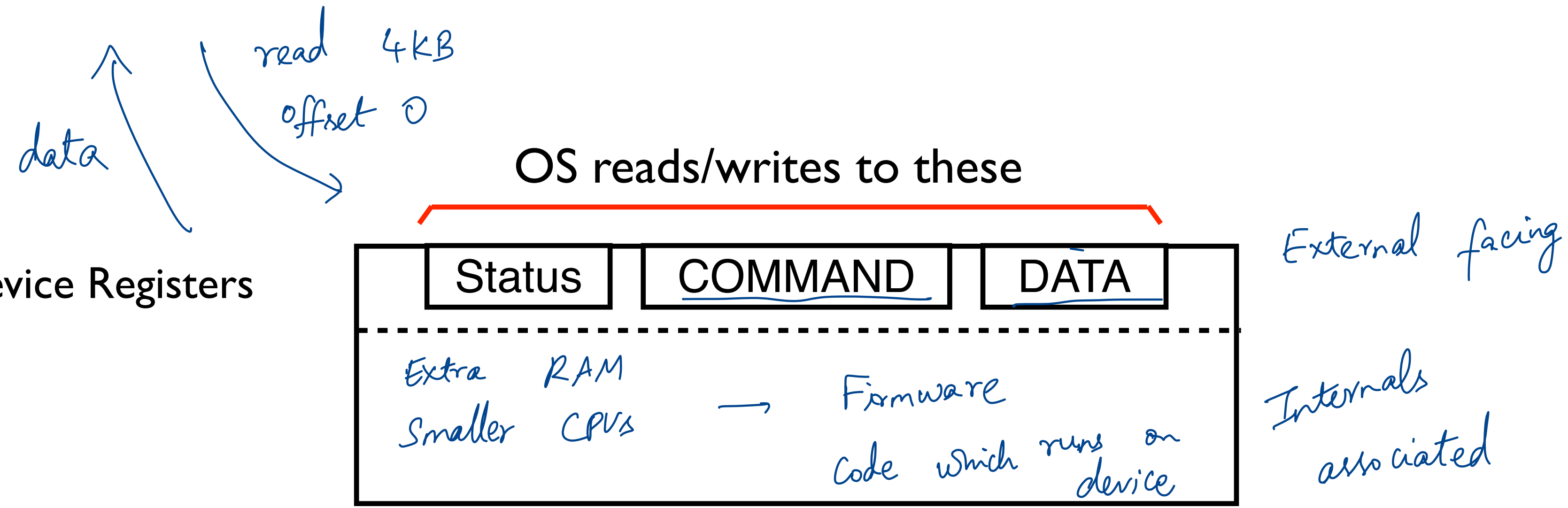
Classic Hierarchy

Fast vs. Number of devices



GPUs or display Cards
Graphics
PCIe Graphics
10s of GB/s
CPU
Memory Interconnect
Memory
DMI
PCIe
I/O Chip
eSATA
Disk
Di
Di
Di
Network
USB
Keyboard
Mouse
USB drive

CANONICAL DEVICE



- Status checks: polling *vs.* interrupts

  Data transfer

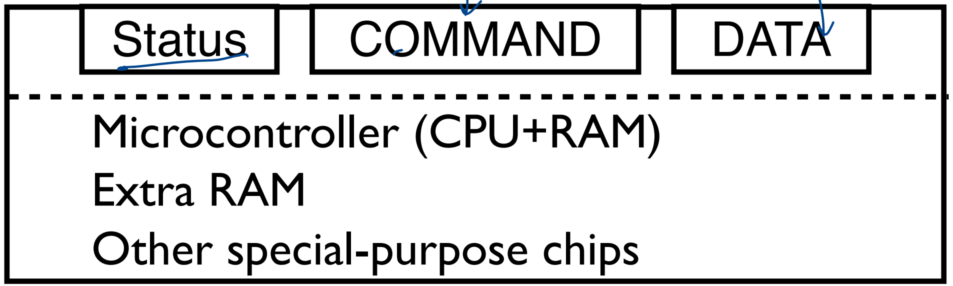
  Control: Invoking I/O

EXAMPLE WRITE PROTOCOL

WRITE offset 24

Populated by OS

write operation to a disk

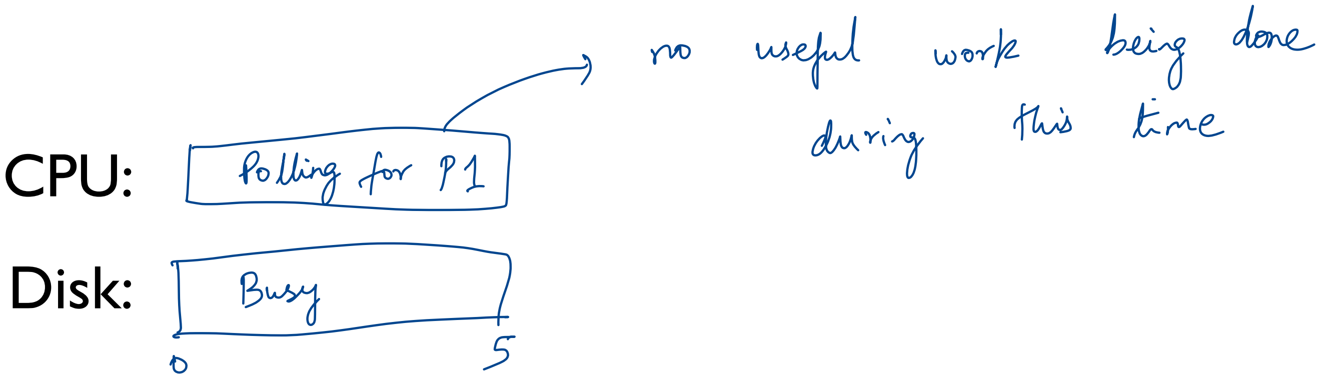



```
while (STATUS == BUSY)
    ; // spin
Write data to DATA register
Write command to COMMAND register
while (STATUS == BUSY)
    ; // spin
```

Polling, waiting for device to be ready

512 bytes of data

- Checks if device has completed this operation

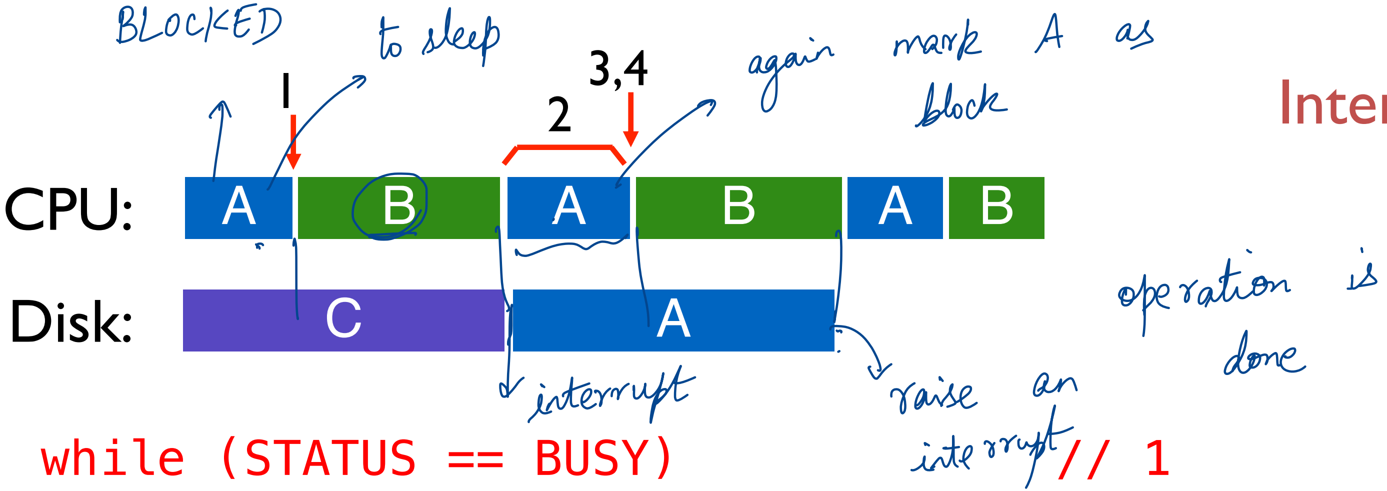



```
while (STATUS == BUSY)            // 1
  ;
Write data to DATA register       // 2
Write command to COMMAND register // 3
while (STATUS == BUSY)            // 4
  ;
```

Interrupts!

Timer interrupts

Page faults




```
while (STATUS == BUSY)                  // 1
      wait for interrupt;
Write data to DATA register             // 2
Write command to COMMAND register       // 3
while (STATUS == BUSY)                  // 4
      wait for interrupt;
```

Interrupts typically improve CPU utilization

INTERRUPTS VS. POLLING

Are interrupts always better than polling?

Fast device: Better to spin than take interrupt overhead

- Device time unknown? Hybrid approach (spin then use interrupts)

Flood of interrupts arrive

- Can lead to livelock (always handling interrupts)
- Better to ignore interrupts while make some progress handling them

Other improvement

- Interrupt coalescing (batch together several interrupts)

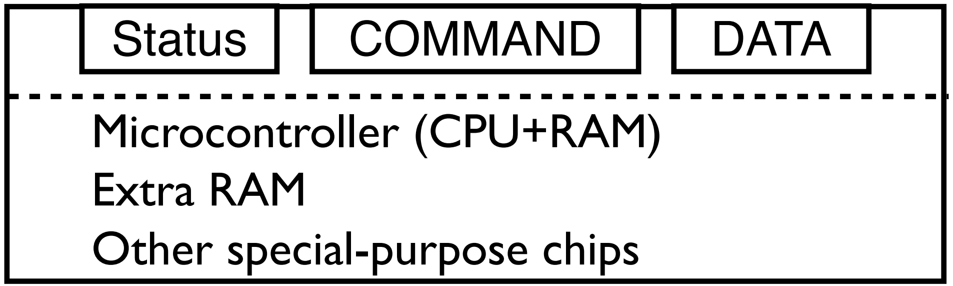
poll

approximation

not making useful progress

number of I/O requests → handle all of them at once!

PROTOCOL VARIANTS

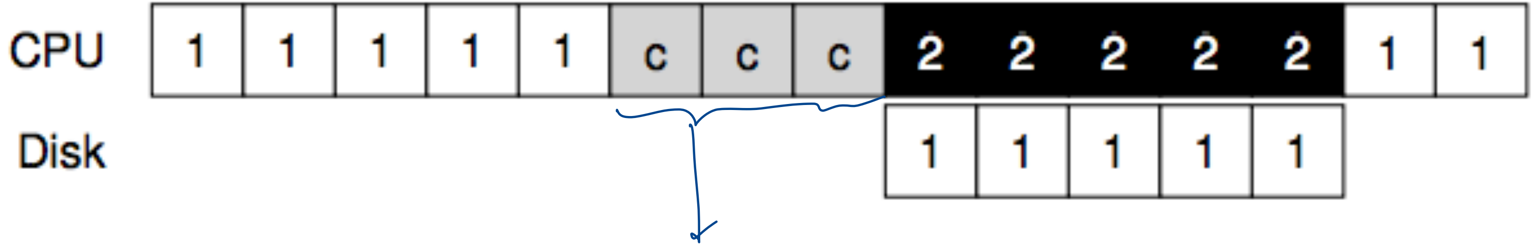


~~Status checks: polling vs. interrupts~~

- Data transfer
- Control: Invoking I/O

DATA TRANSFER COSTS

CPU is actively involved → not using CPU to do other things



CPU is copying data to the disk

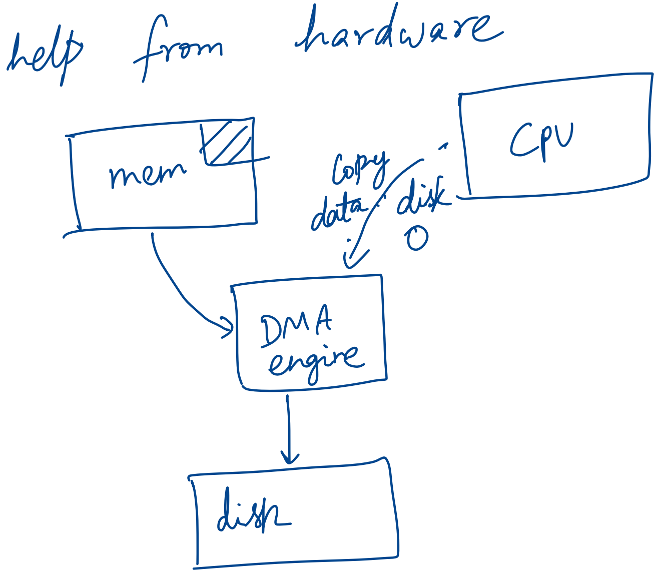
PROGRAMMED I/O VS. DIRECT MEMORY ACCESS

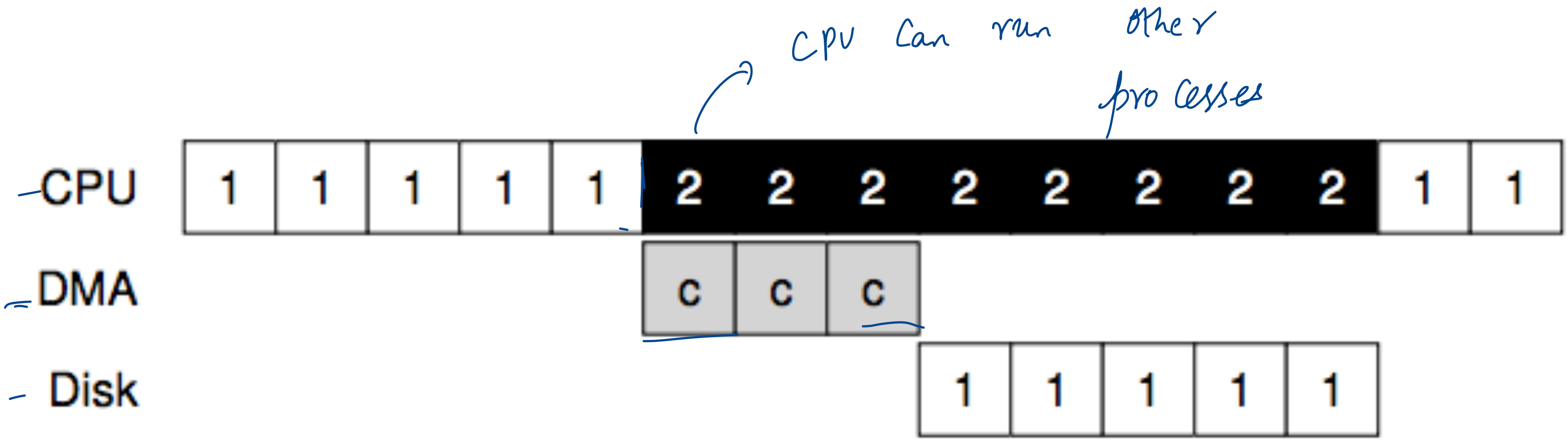
PIO (Programmed I/O):

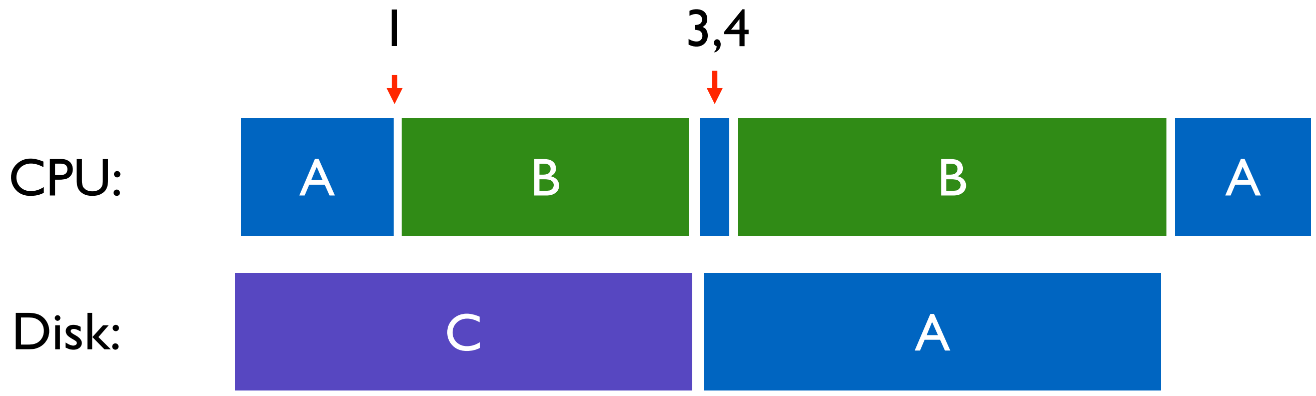
- CPU directly tells device what the data is

DMA (Direct Memory Access):

- CPU leaves data in memory
- Device reads data directly from memory




CPU can run other processes
CPU
1
1
1
1
1
2
2
2
2
2
2
2
2
1
1
DMA
c
c
c
Disk
1
1
1
1
1



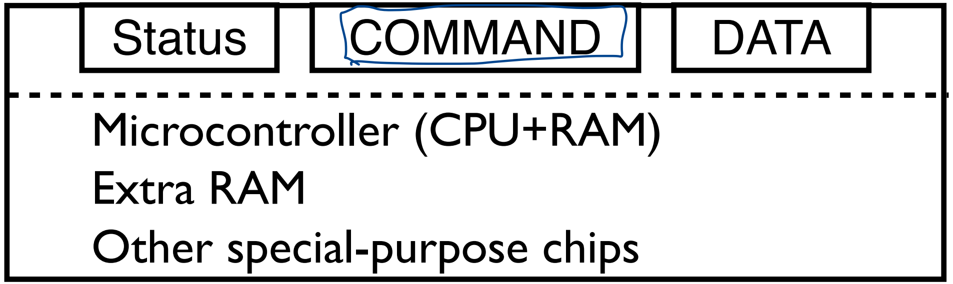

```
while (STATUS == BUSY)            // 1
  ;
Write data to DATA register       // 2
Write command to COMMAND register // 3
while (STATUS == BUSY)            // 4
  ;
```

→ Interrupts (1)

~~Write data to DATA register // 2~~ → DMA

→ Interrupts (4)

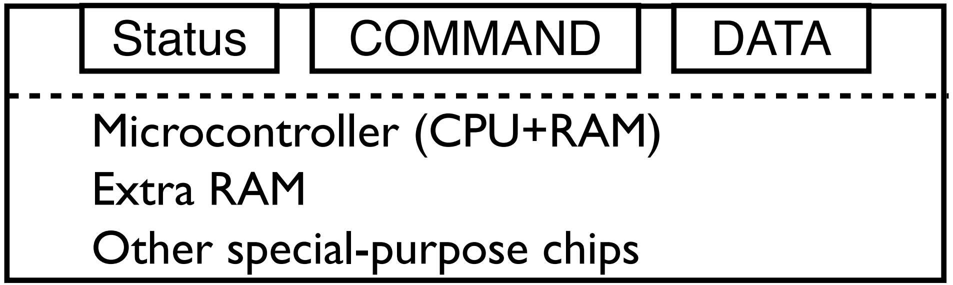
PROTOCOL VARIANTS



Status checks: polling *vs.* interrupts

PIO vs DMA

Control: Invoking I/O




```
while (STATUS == BUSY)                 // 1
  ;
Write data to DATA register            // 2
Write command to COMMAND register      // 3
while (STATUS == BUSY)                 // 4
  ;
```

SPECIAL INSTRUCTIONS VS. MEM-MAPPED I/O

x86 instructions → Device

IN REGISTER PORT

OUT REGISTER PORT

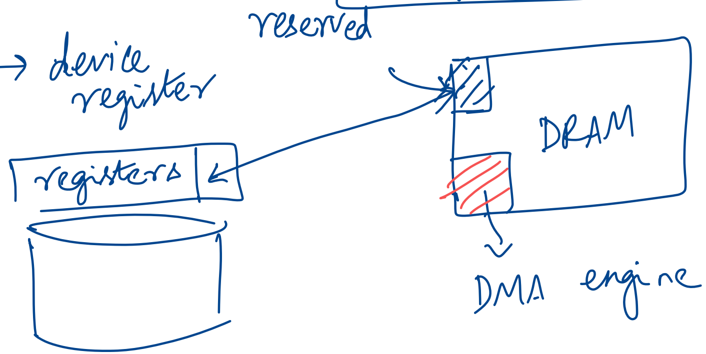
Special instructions

- each device has a port
- in/out instructions (x86) communicate with device

OUT EAX 1 — write contents of EAX to command of PORT 1

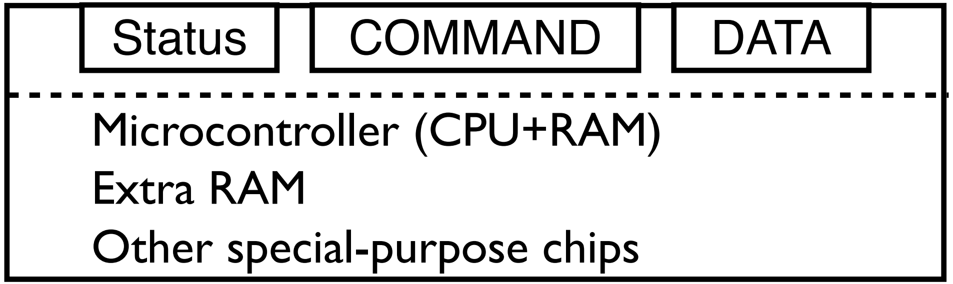
Memory-Mapped I/O

- H/W maps registers into address space
- loads/stores sent to device — store mem → device register



Doesn't matter much (both are used)

PROTOCOL VARIANTS

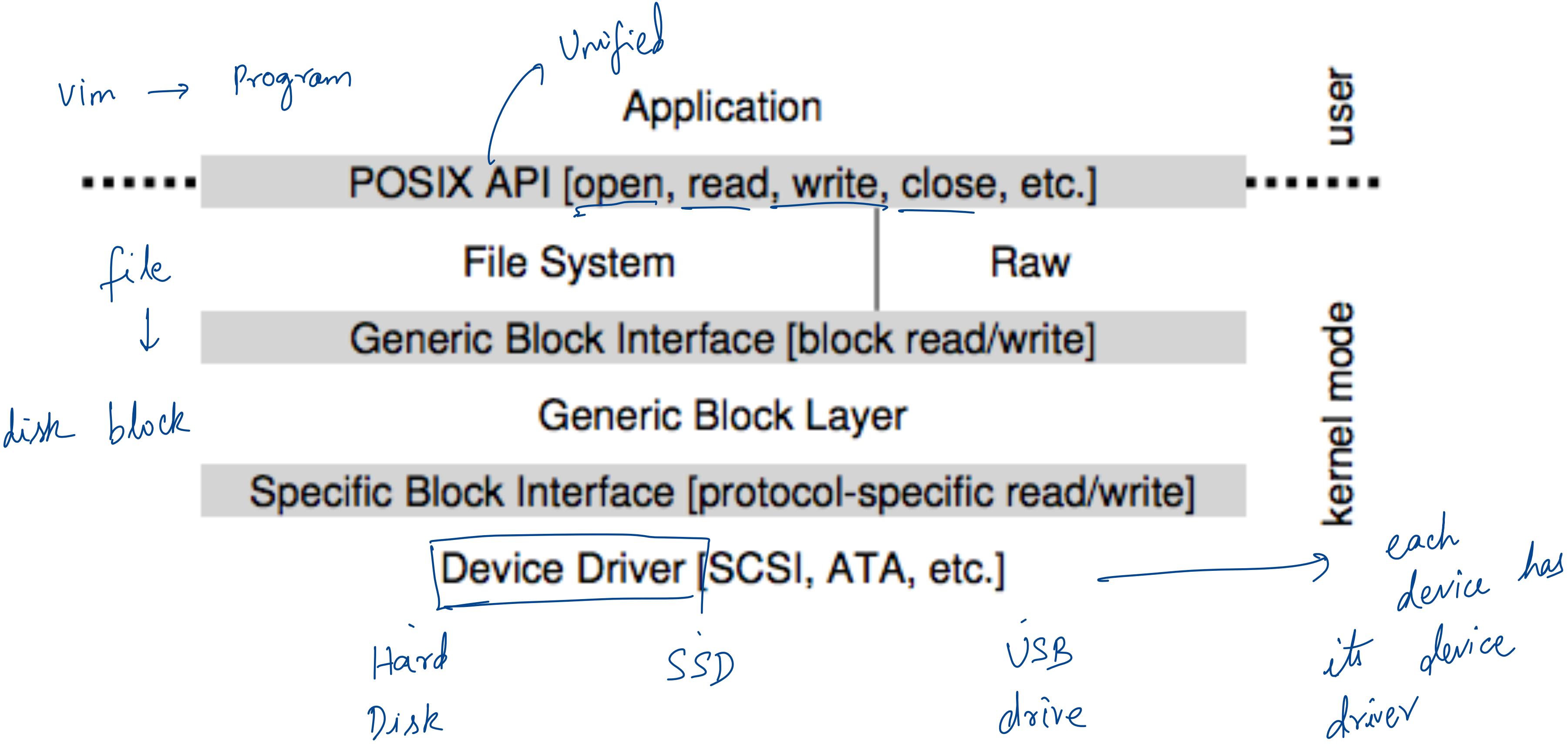


Status checks: polling *vs.* interrupts

PIO vs DMA

Special instructions vs. Memory mapped I/O

DEVICE DRIVERS



VARIETY IS A CHALLENGE

Problem:

- many, many devices
- each has its own protocol

Modularity → Stability

How can we avoid writing a slightly different OS for each H/W combination?

Write device driver for each device

Drivers are **70%** of Linux source code → millions of code

QUIZ 20

https://tinyurl.com/cs537-sp23-quiz20

If you have a fast non-volatile memory based storage device, which approach would work better?

→ Polling is better if device is fast
avoid interrupt overheads

What part of a device protocol is improved by using DMA ?

Wait for device to be free
Write data
write command
Wait for operation to complete

HARD DISKS

HARD DISK INTERFACE

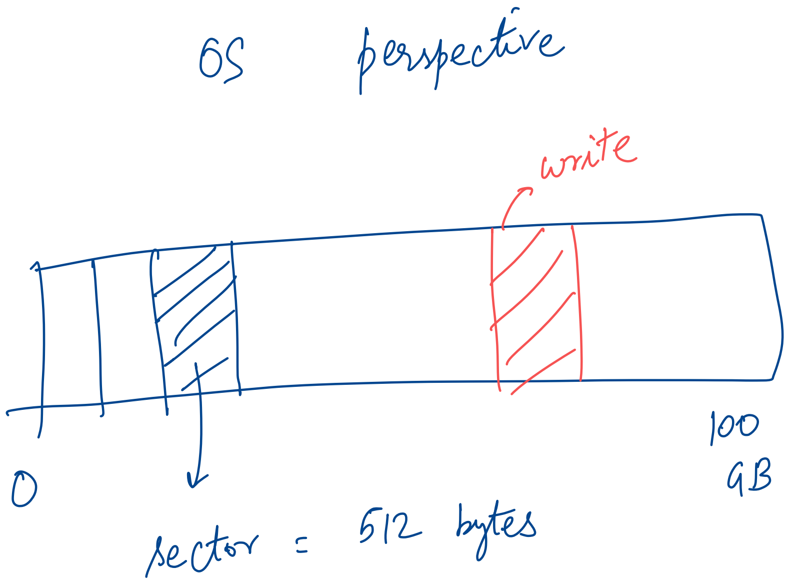
Disk has a sector-addressable address space

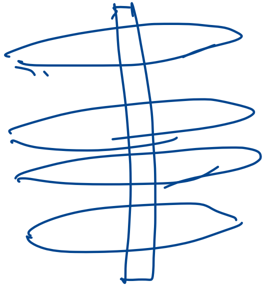
Appears as an array of sectors

Sectors are typically 512 bytes

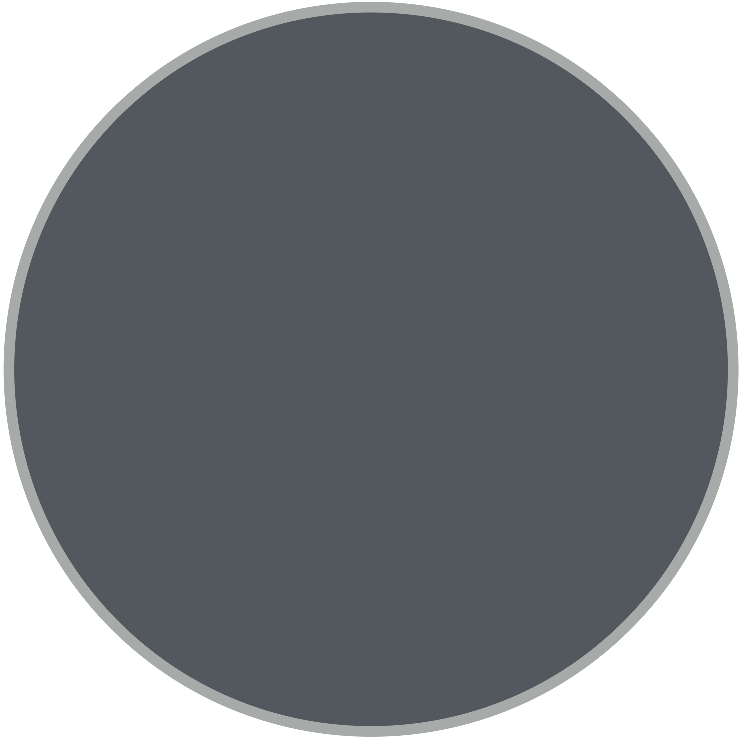
Main operations: reads + writes to sectors

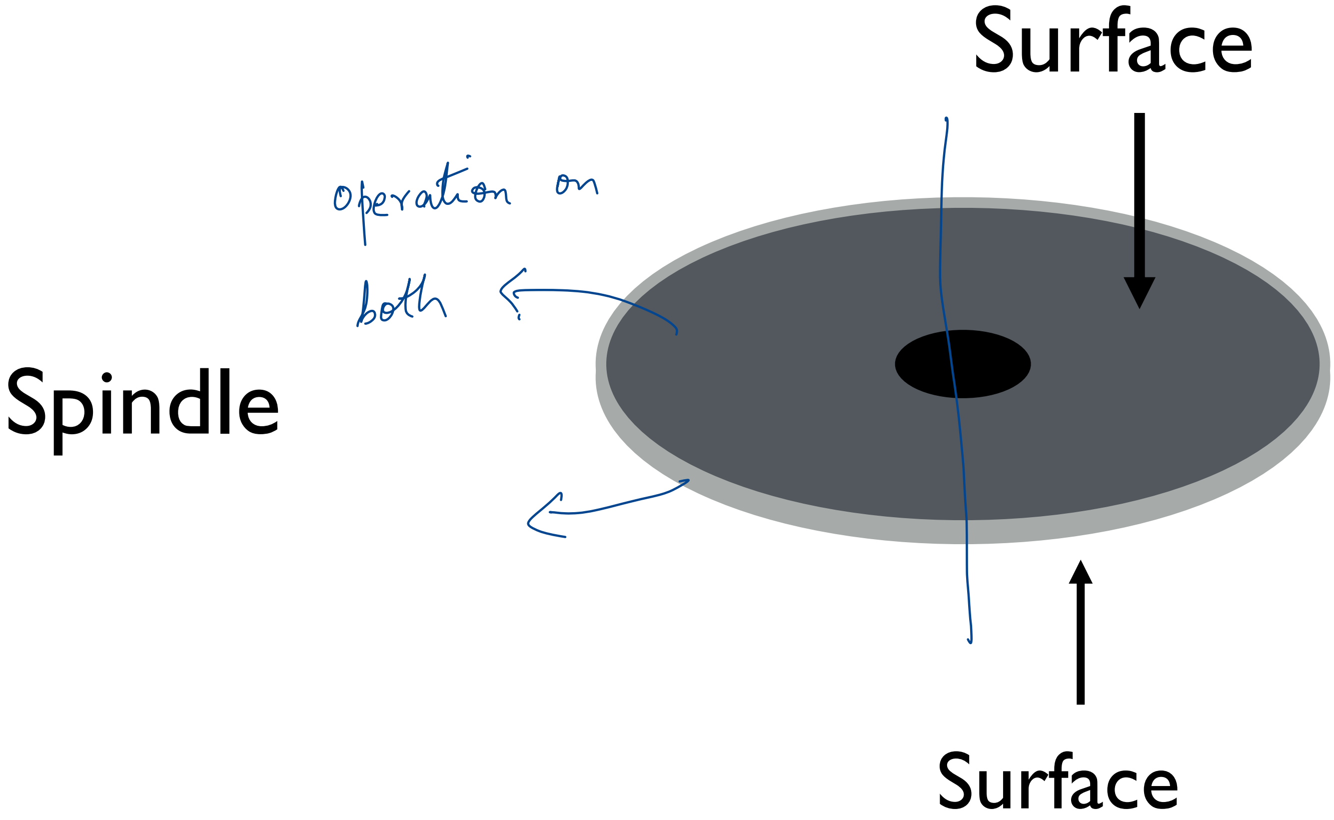
Mechanical and slow (?)





Platter




Surface
operation on
both
Spindle
Surface

10,000 rotations → 60,000 ms

1 rotation → 6 ms

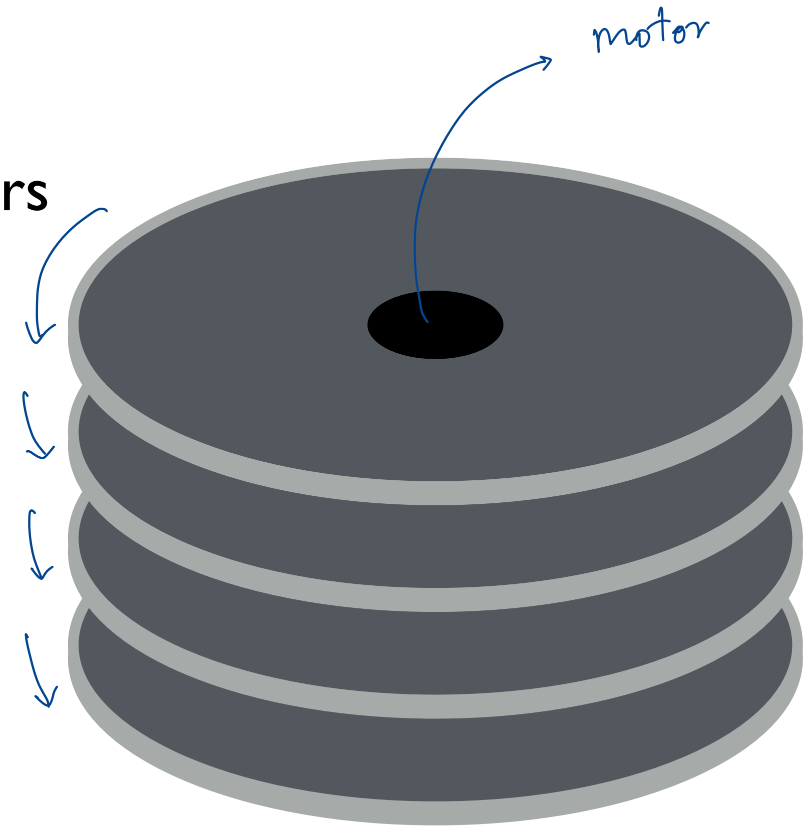
RPM?

Motor connected to spindle spins platters

Rate of rotation: RPM

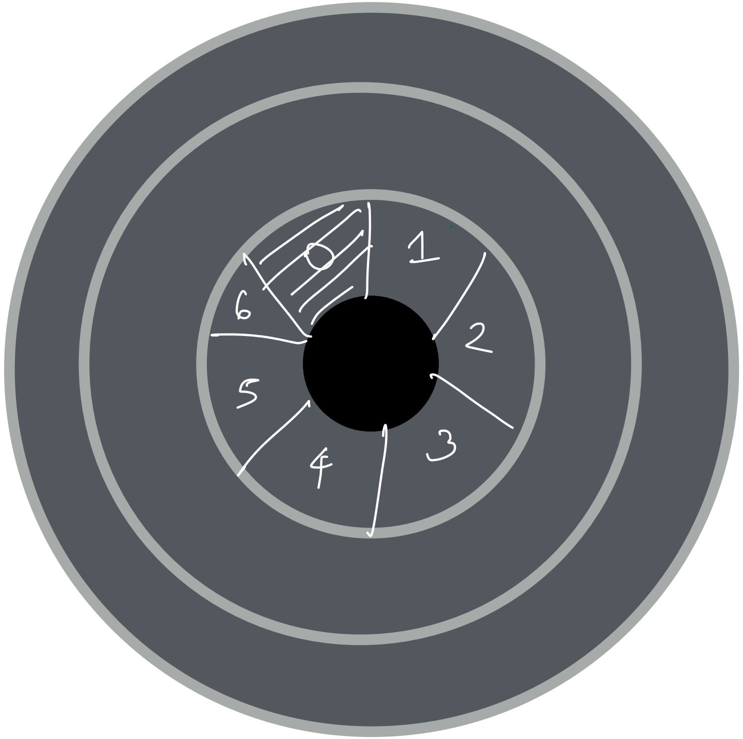
10000 RPM → single rotation is 6 ms

7500 RPM → rotations per minute

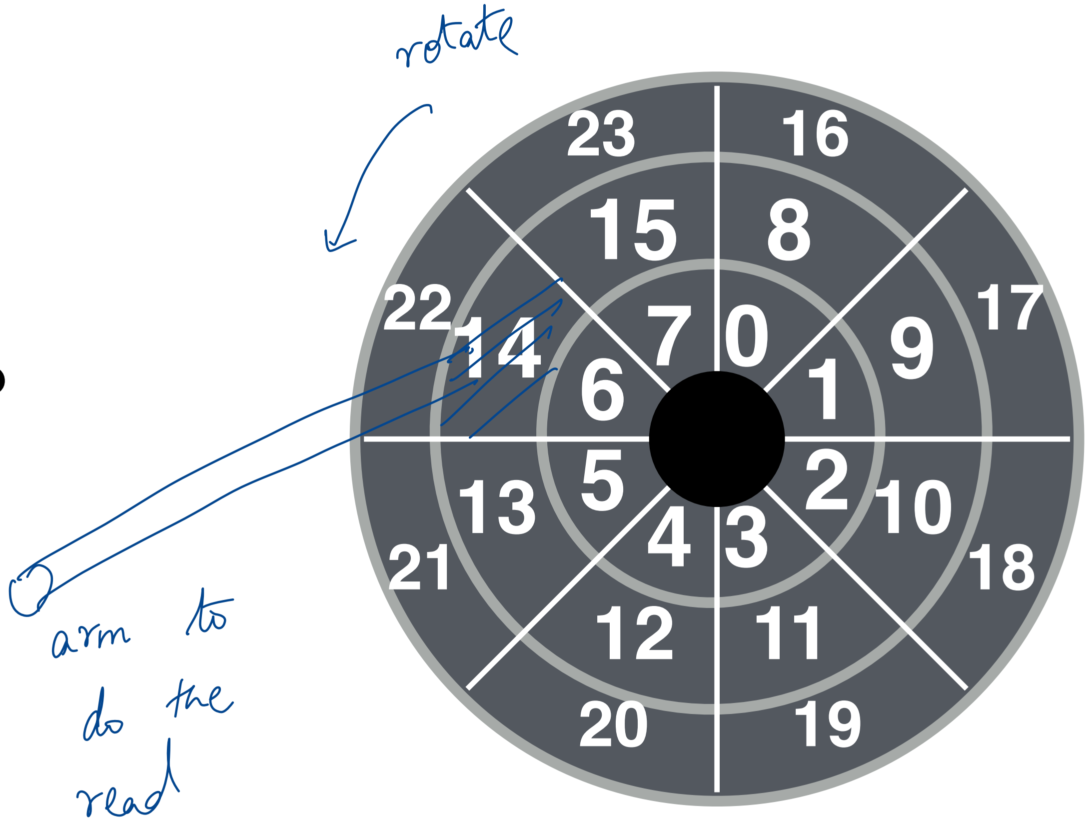


Surface is divided into rings: tracks

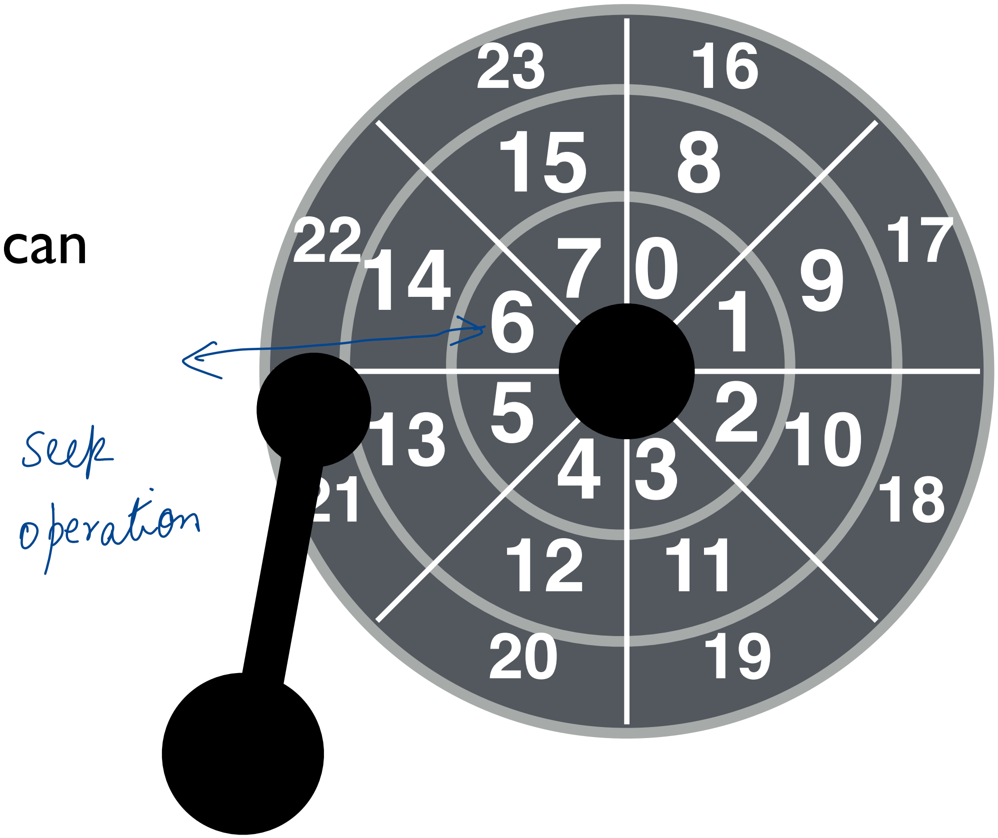
Stack of tracks(across platters): cylinder



Tracks are divided into numbered sectors

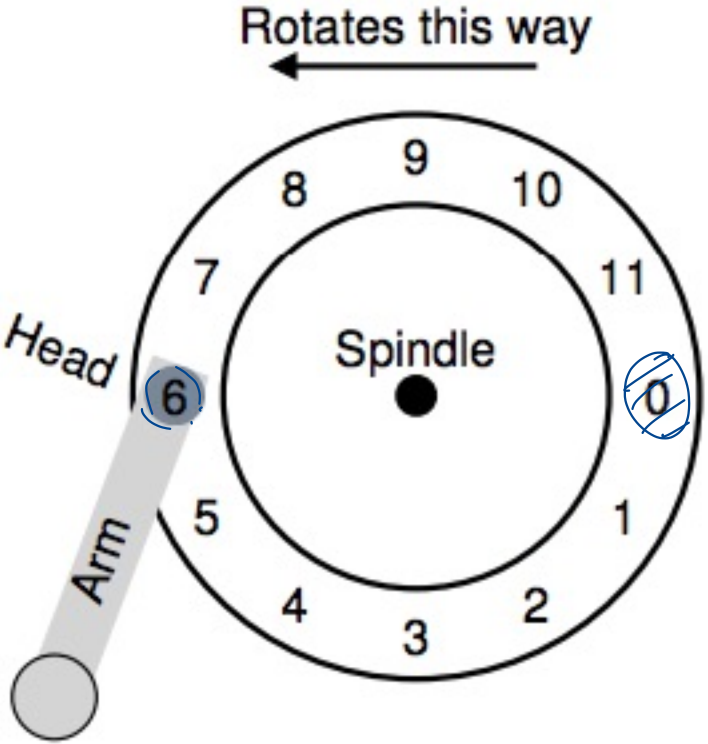


Heads on a moving arm can read from each surface.



READING DATA FROM DISK

10,000 RPM



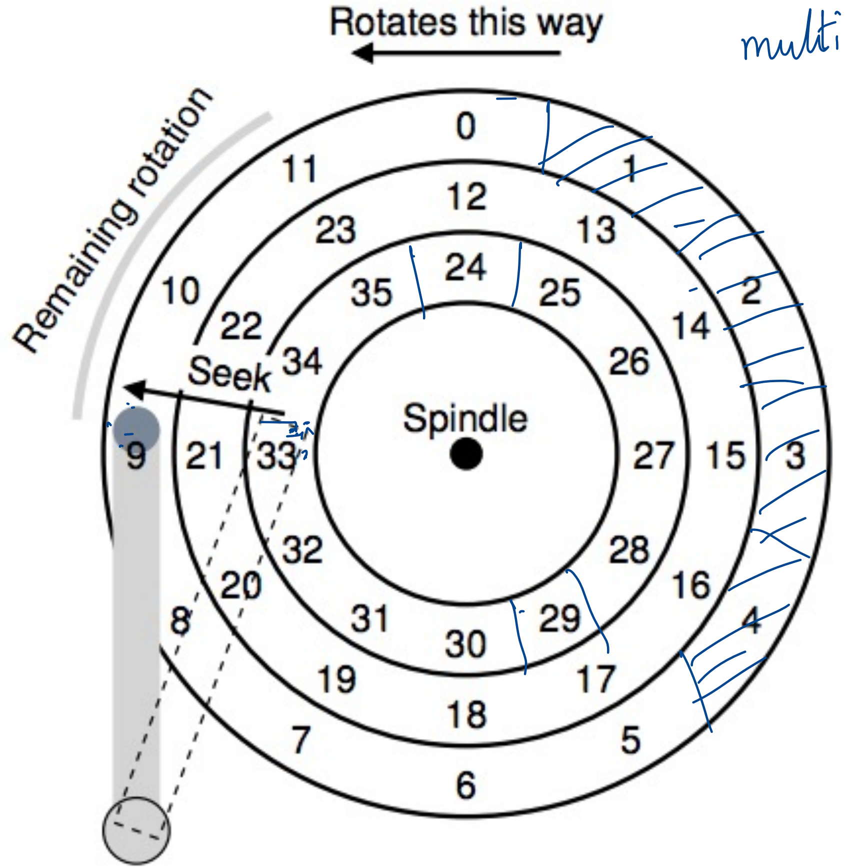
Rotational delay

→ Wait for half a rotation to complete

Disk read time

3ms + <???> = time for ½ rotation + data transfer time

READING DATA FROM DISK



multi zoned

Seek Time

- → Time for arm to move to the right track
- → While seek is going on, disk is also rotating

TIME TO READ/WRITE

Three components:

Time = seek + rotation + transfer time

= how far disk arm need to move + how much time does it take for 1 rotation + $\frac{\text{data size}}{\text{link speed}}$

SEEK, ROTATE, TRANSFER

inner most track
↓
outer most track

Seek cost: Function of cylinder distance

- Not purely linear cost
- Must accelerate, coast, decelerate, settle
- Settling alone can take 0.5 - 2 ms

Entire seeks often takes 4 - 10 ms

Average seek = 1/3 of max seek

Depends on rotations per minute (RPM)

- 7200 RPM is common, 15000 RPM is high end

Average rotation? → 1/2 time taken for a full rotation

Pretty fast: depends on RPM and sector density.

100+ MB/s is typical for maximum transfer rate

QUIZ 21

https://tinyurl.com/cs537-sp23-quiz21

What is the time for 4KB random read?

	Cheetah 15K.5	Barracuda
Capacity	300 GB	1 TB
RPM	15,000	7,200
Average Seek	4 ms	9 ms
Max Transfer	125 MB/s	105 MB/s
Platters	4	4
Cache	16 MB	16/32 MB
Connects via	SCSI	SATA

NEXT STEPS

Advanced disk features

Scheduling disk requests

Midterm 2 soon!