PERSISTENCE: I/O DEVICES

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CS 537, Spring 2019

ADMINISTRIVIA

Project 4a: Out tonight, due on April 4th

Work in groups of up to two

Grades: Project 2b, 3, midterm by tomorrow!

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

1. Virtualization

2. Concurrency

3. Persistence

VIRTUALIZATION

Make each application believe it has each resource to itself

CPU and Memory

Abstraction: Process API, Address spaces

Mechanism:

Limited direct execution, CPU scheduling

Address translation (segmentation, paging, TLB)

Policy: MLFQ, LRU etc.

CONCURRENCY

Events occur simultaneously and may interact with one another

Need to

- Hide concurrency from independent processes
- Manage concurrency with interacting processes

Provide abstractions (locks, semaphores, condition variables etc.)

Correctness: mutual exclusion, ordering → T1 after T2

Performance: scaling data structures, fairness

Common Bugs!

Producer Consumer queues

OPERATING SYSTEMS: THREE EASY PIECES

Three conceptual pieces

1. Virtualization

2. Concurrency

3. Persistence

MOTIVATION

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

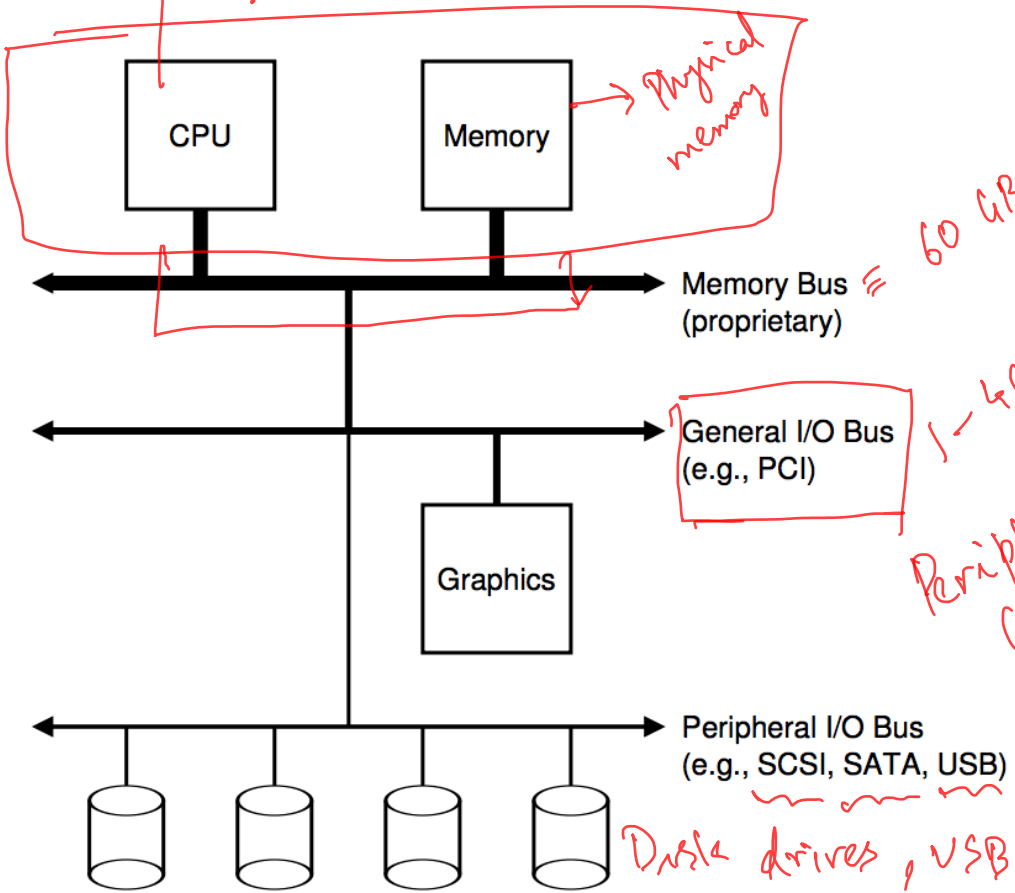
keyboard, display, disks

This per is o I/o devices

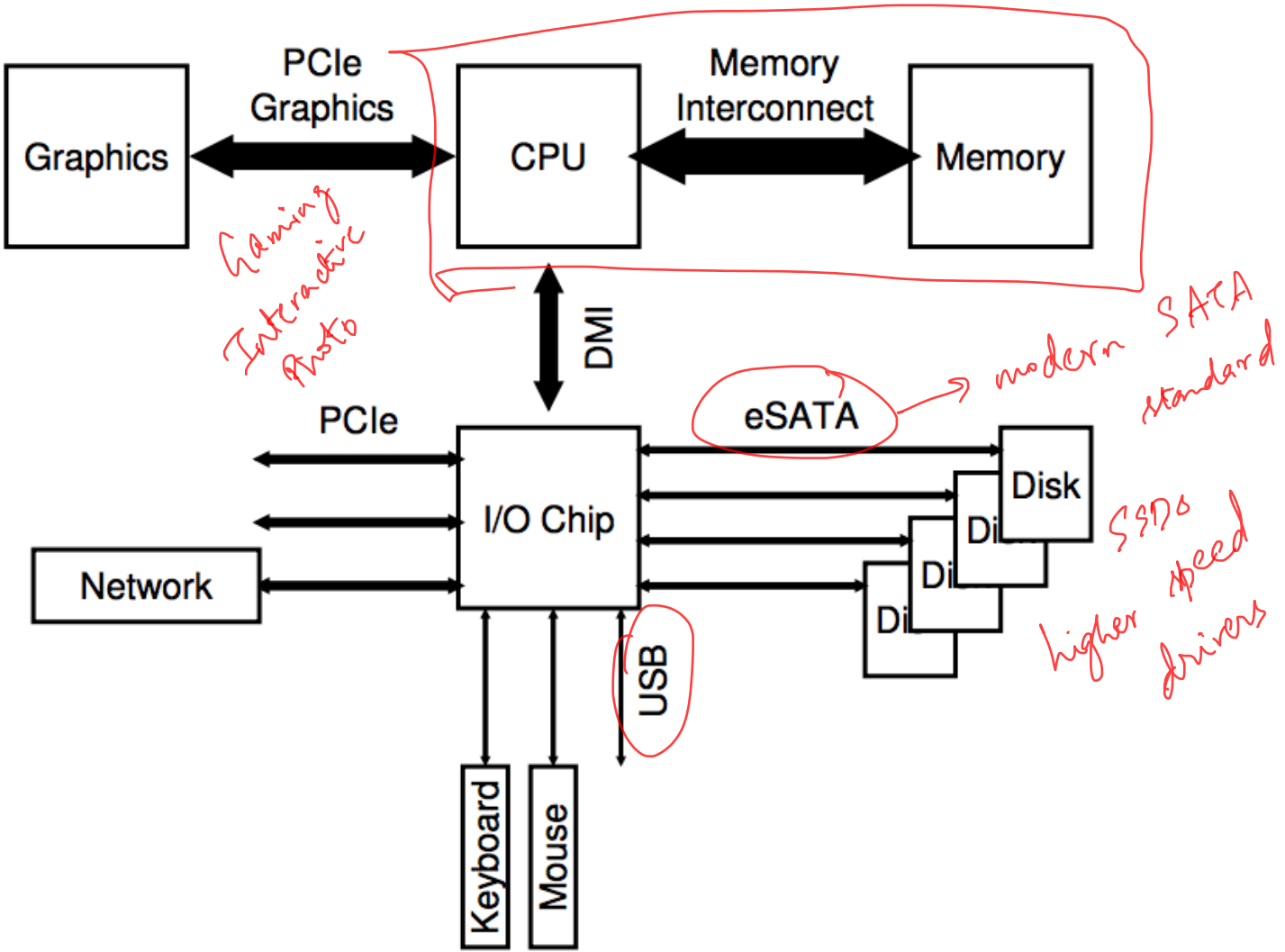
We want:

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

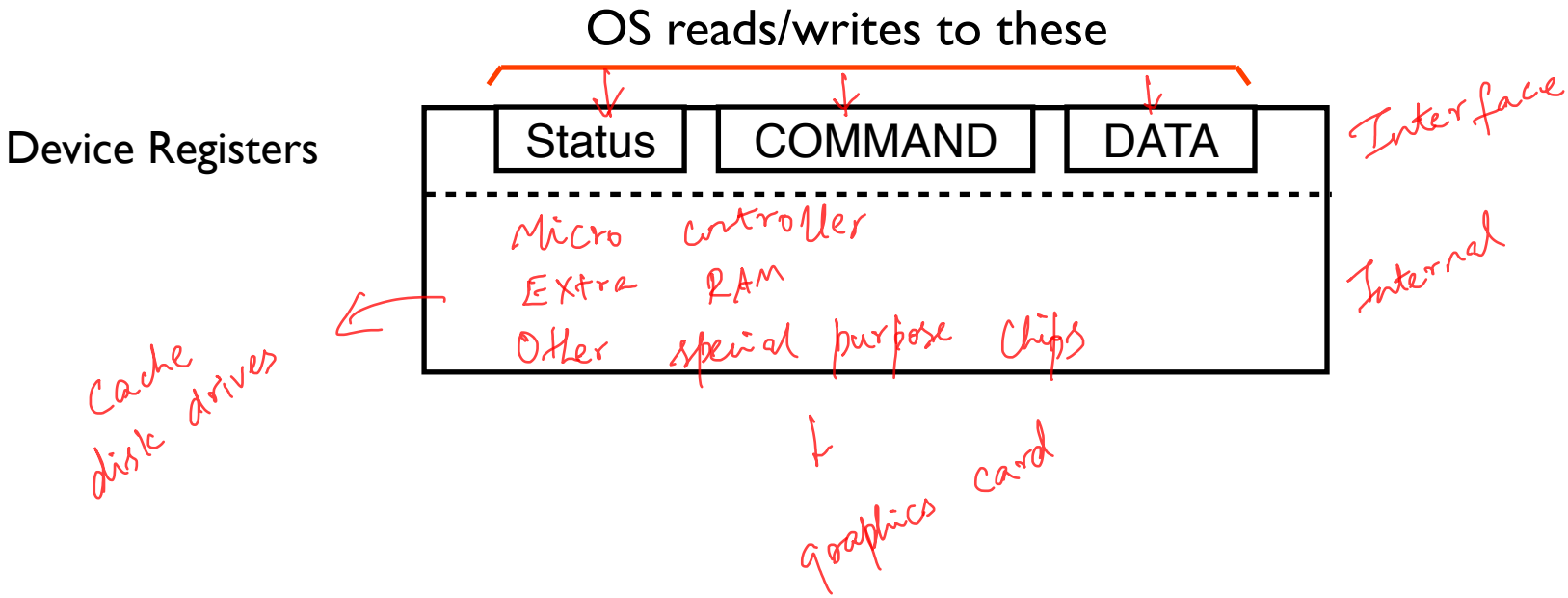
HARDWARE SUPPORT FOR I/O



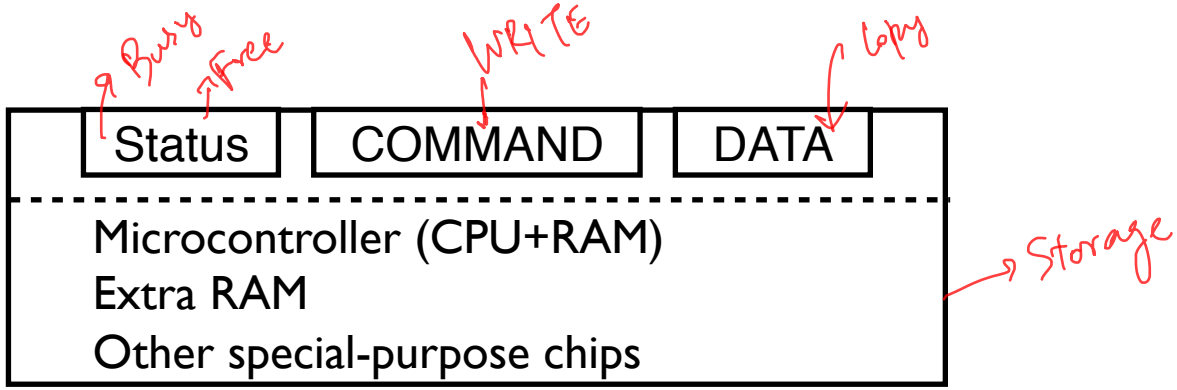
Why use hierarchical buses?


Graphics
PCIe
Graphics
CPU
Memory
Interconnect
Memory
DMI
PCIe
I/O Chip
eSATA
Disk
Network
USB
Keyboard
Mouse

CANONICAL DEVICE

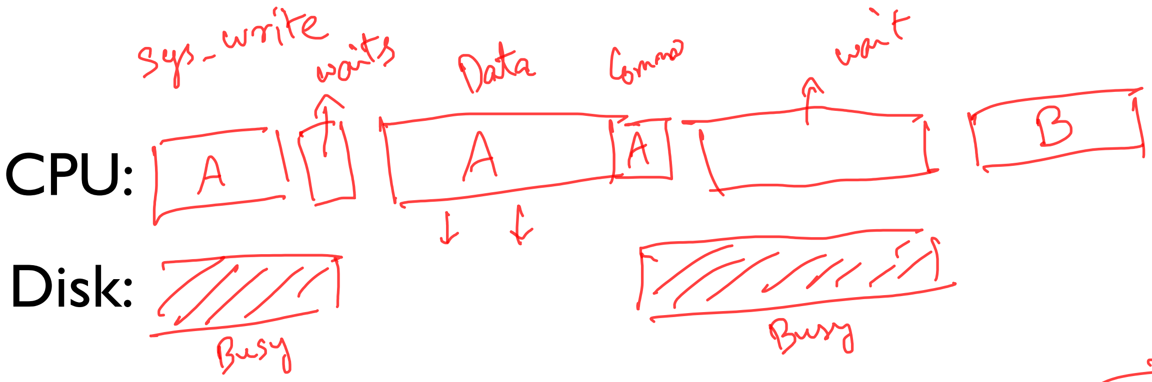


EXAMPLE WRITE PROTOCOL

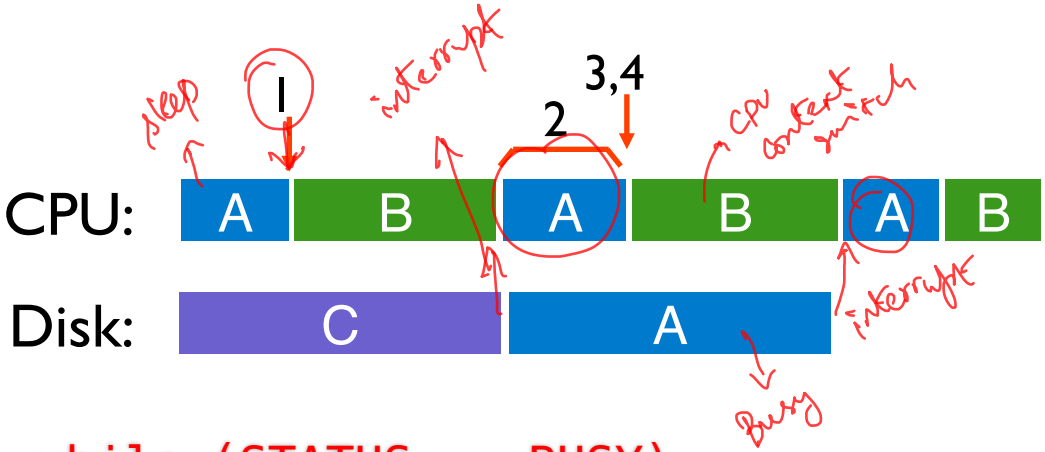



```
1  while (STATUS == BUSY)
     ; // spin
2  Write data to DATA register
3  Write command to COMMAND register
4  while (STATUS == BUSY)
     ; // spin
```

Checks if device is free




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



Interrupts!

```
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 VS. POLLING

Are interrupts always better than polling?

Fast device: Better to spin than take interrupt overhead

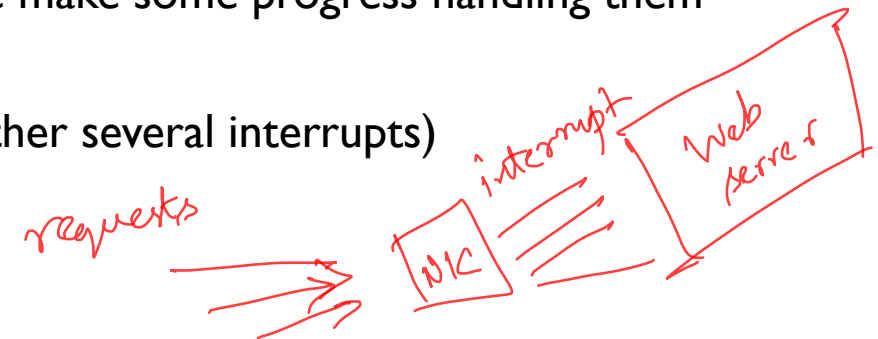
- Device time unknown? Hybrid approach (spin then use interrupts)

Flood of interrupts arrive

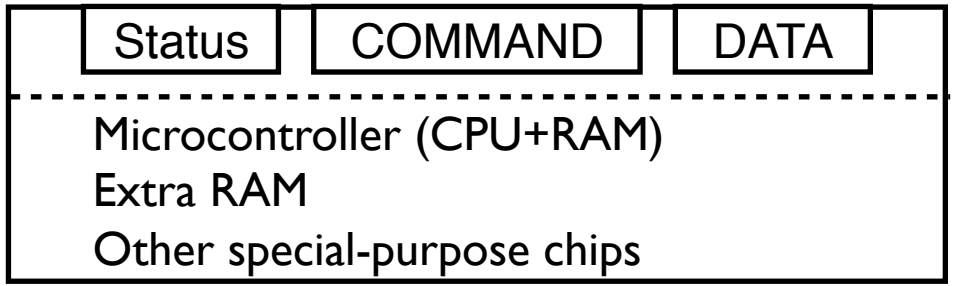
- Can lead to livelock (always handling interrupts)
- Better to ignore interrupts while make some progress handling them

Other improvement

- Interrupt coalescing (batch together several interrupts)

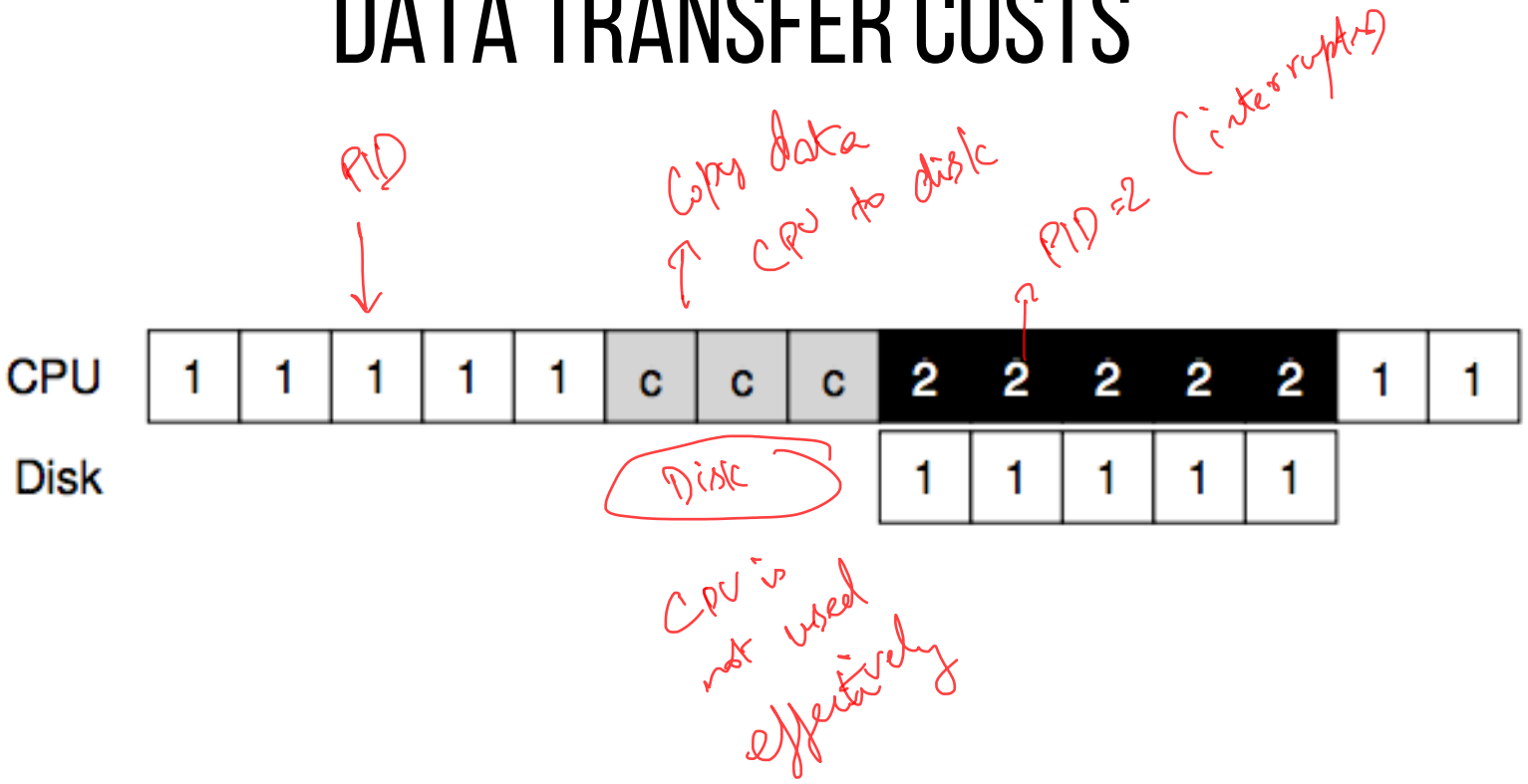


PROTOCOL VARIANTS



Status checks: polling *vs.* interrupts

DATA TRANSFER COSTS



PROGRAMMED I/O VS. DIRECT MEMORY ACCESS

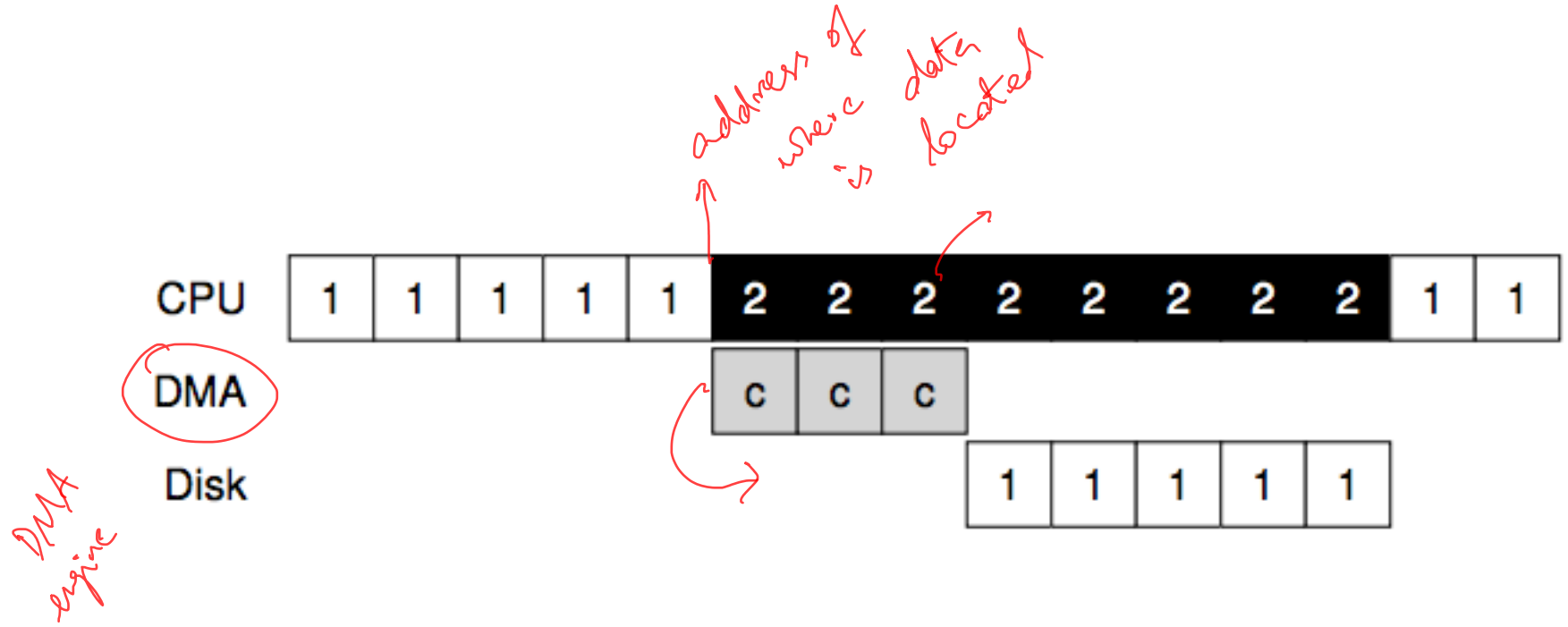
DMA

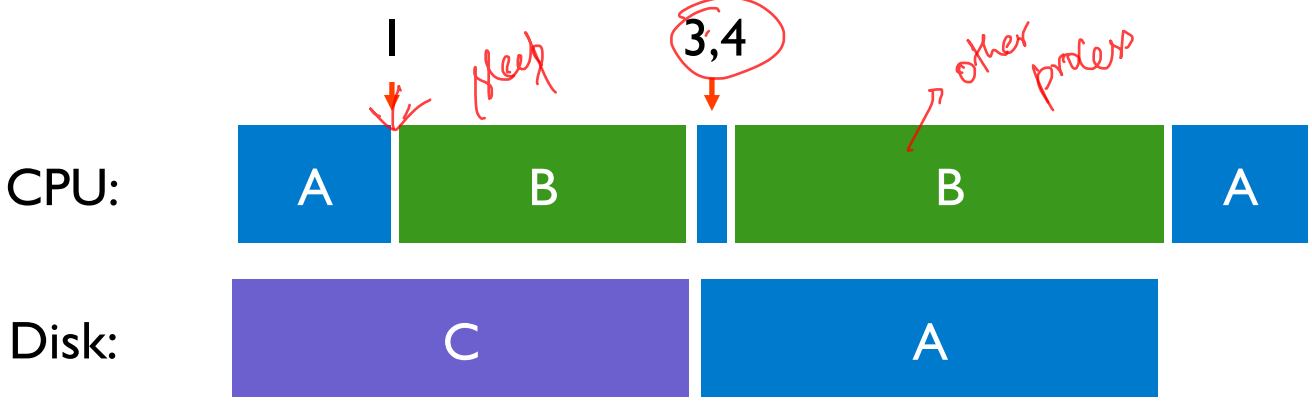
PIO (Programmed I/O):

- CPU directly tells device what the data is

DMA (Direct Memory Access):

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


address of where data is located
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
DMA engine




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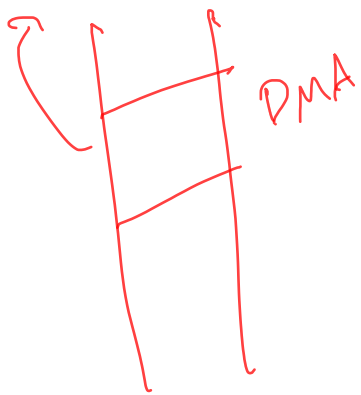
Write command to COMMAND register       // 3
while (STATUS == BUSY)                  // 4
   ;
```



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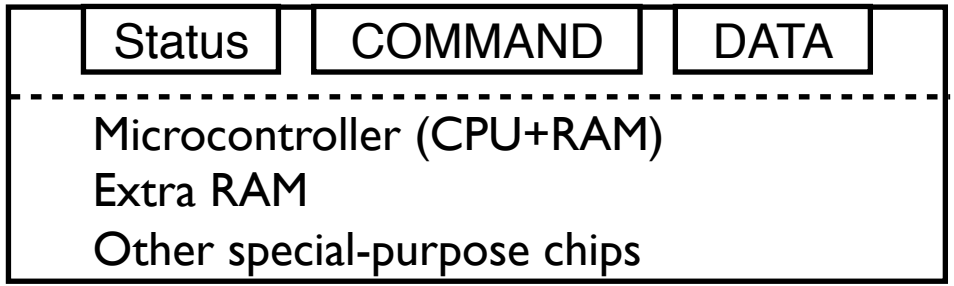
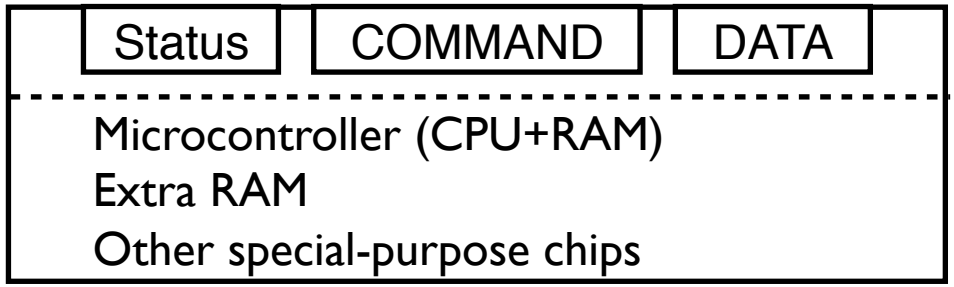


Status checks: polling *vs*. interrupts

PIO vs DMA

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while (STATUS == BUSY)                  // 4
   ;
```

SPECIAL INSTRUCTIONS VS. MEM-MAPPED I/O

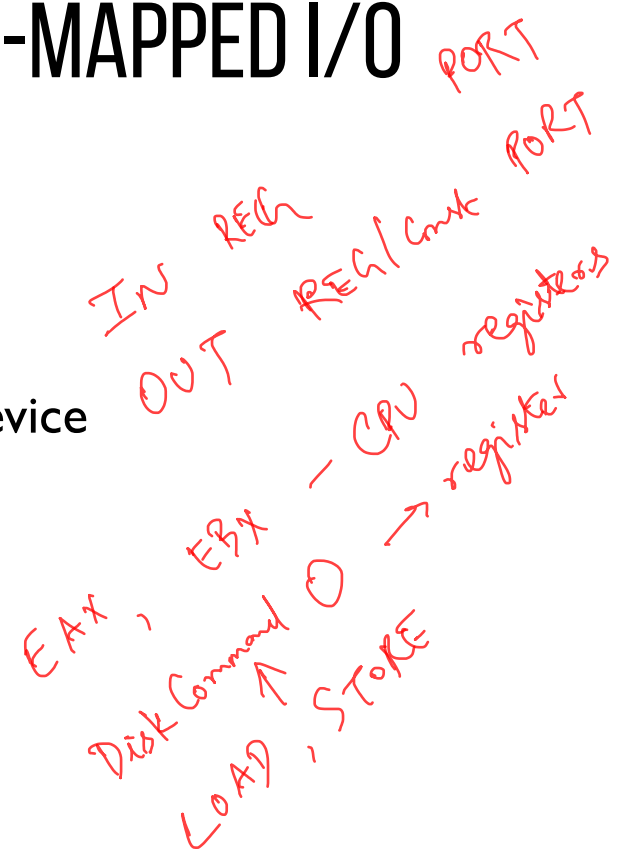
Special instructions

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

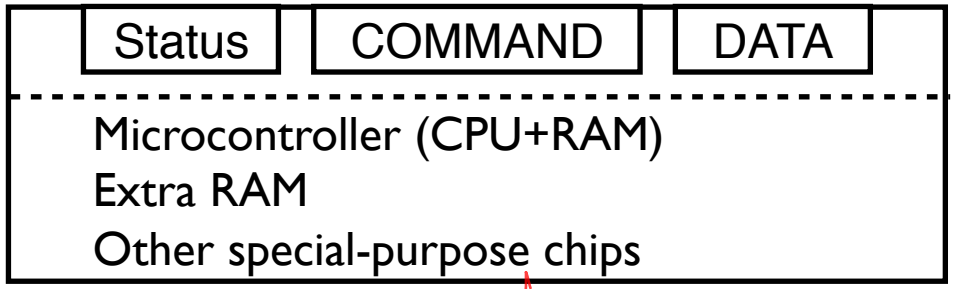
Memory-Mapped I/O

- H/W maps registers into address space
- loads/stores sent to device

Doesn't matter much (both are used)



PROTOCOL VARIANTS

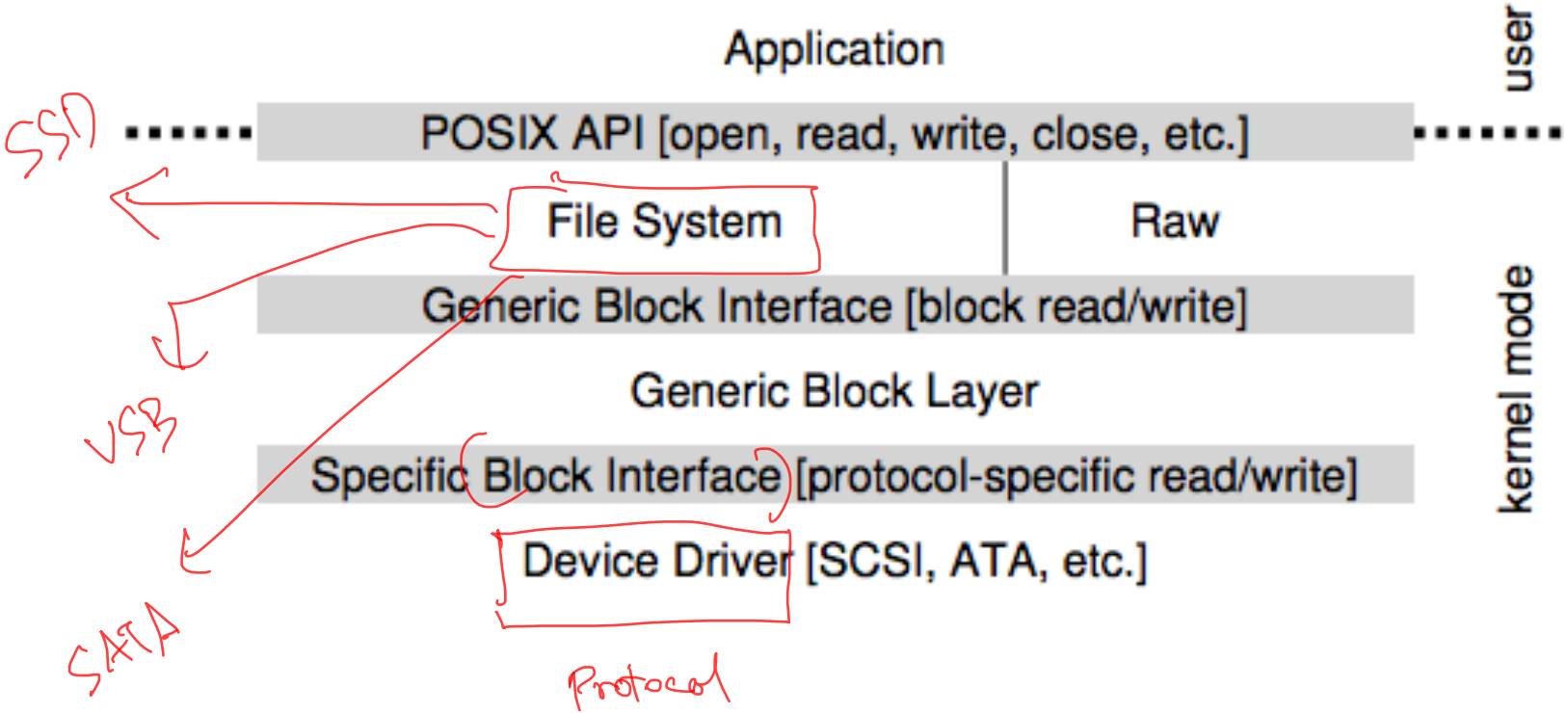


Status checks: polling *vs.* interrupts

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

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

Write device driver for each device

Isolate device driver

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

BUNNY 10

https://tinyurl.com/cs537-sp19-bunny10

BUNNY 10

SSD → solid state devices

new class of storage devices

Intel Optane drive

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

≈ few micro seconds

Polling

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

Data register

HARD DISKS

HARD DISK INTERFACE

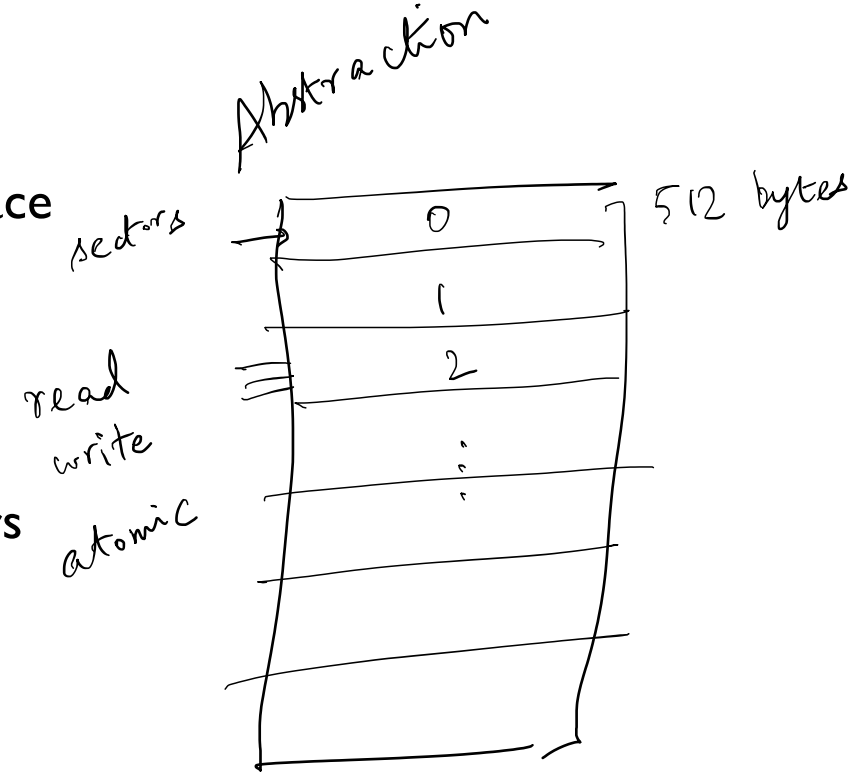
Disk has a sector-addressable address space
    Appears as an array of sectors

Sectors are typically 512 bytes

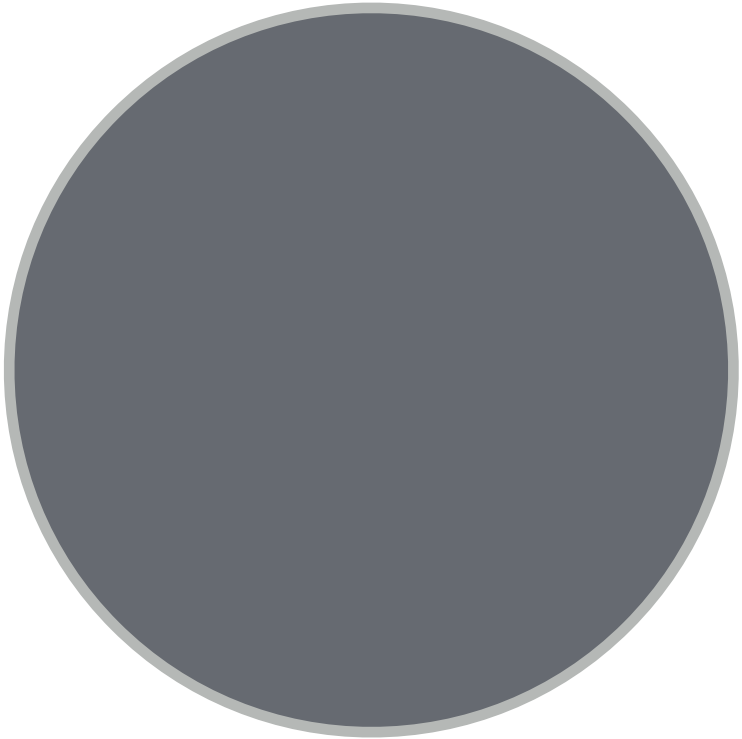
Main operations: reads + writes to sectors

Mechanical and slow (?)

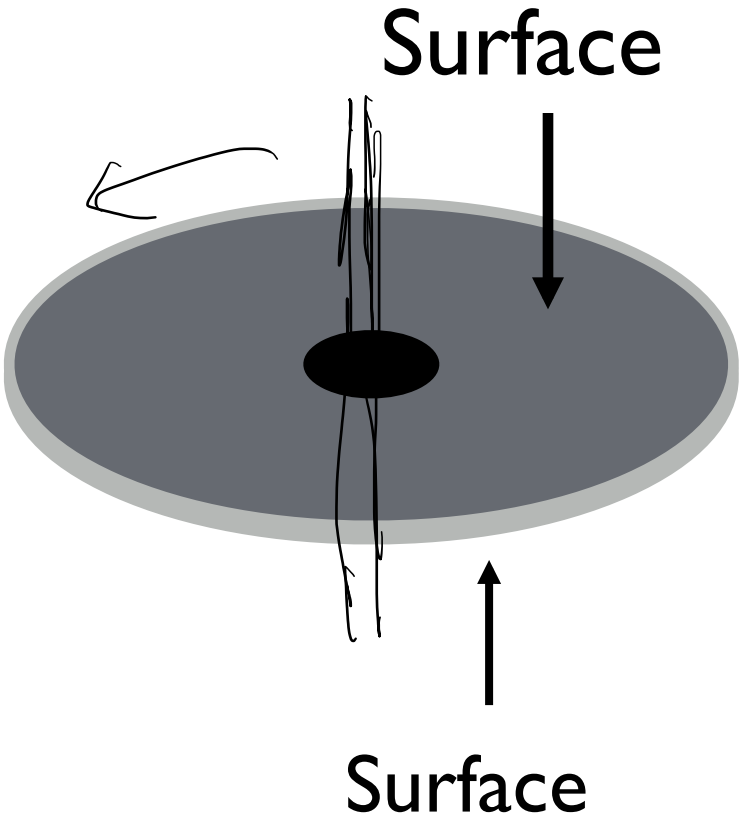
operations



Platter



Spindle

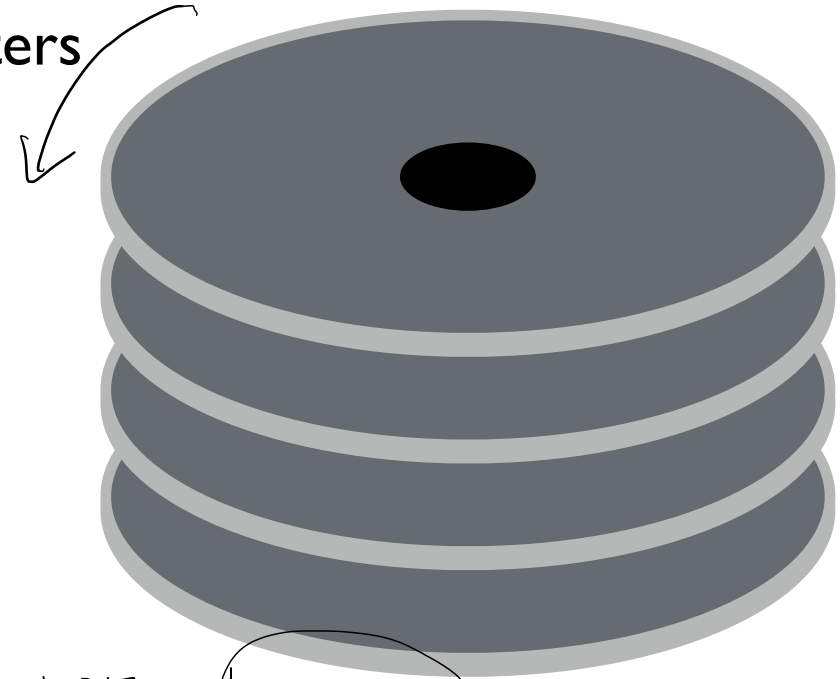


RPM?

Motor connected to spindle spins platters

Rate of rotation: RPM

10000 RPM → single rotation is 6 ms



10000 rotations per min

10,000 rotations per sec

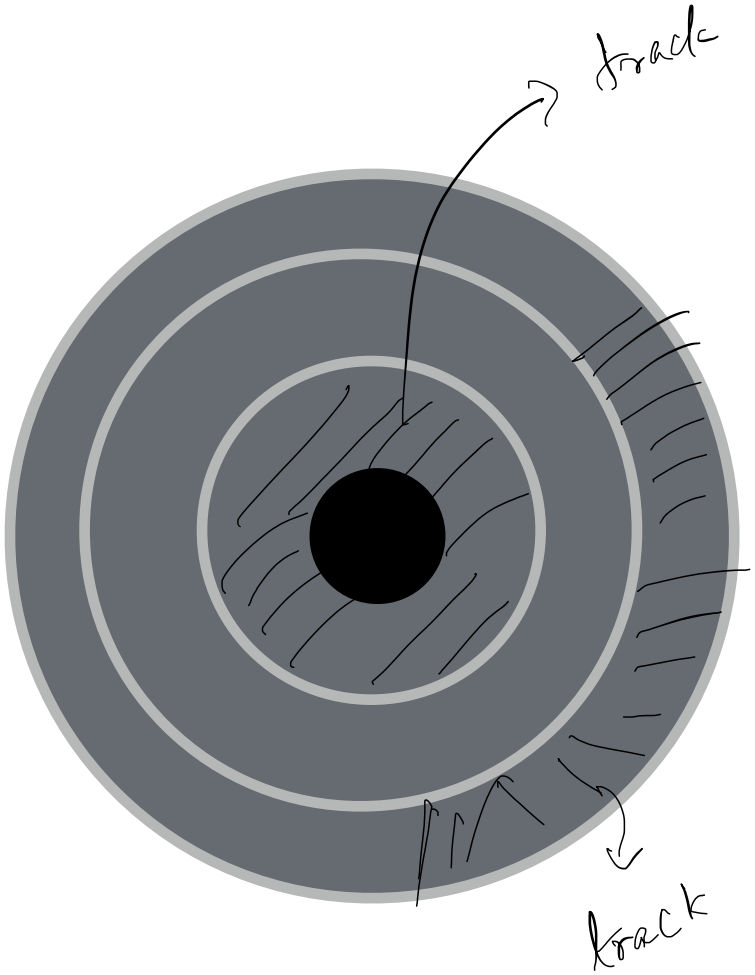
60

1000 ms in 1 s

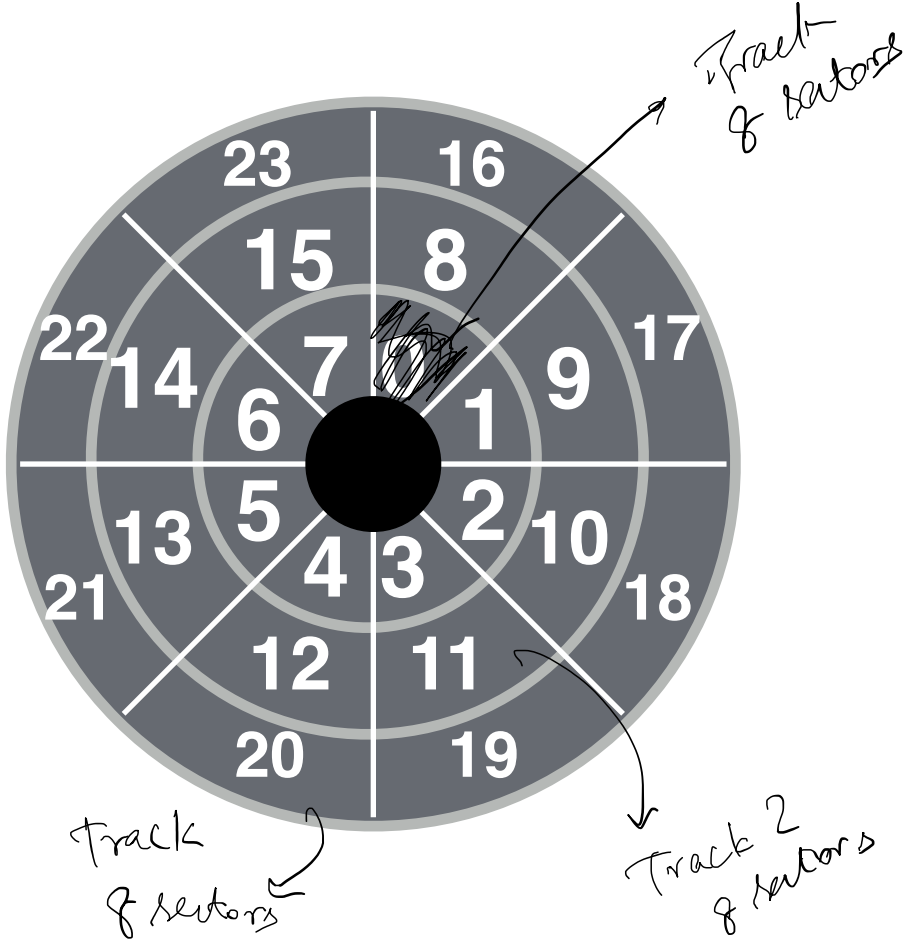
⇒ Latency = $\frac{60}{10,000} \times 1000$ = 6 ms

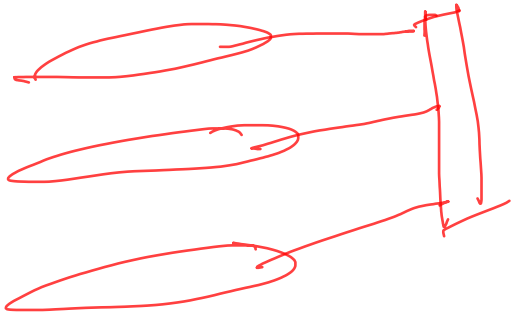
Surface is divided into rings: tracks

Stack of tracks(across platters): cylinder

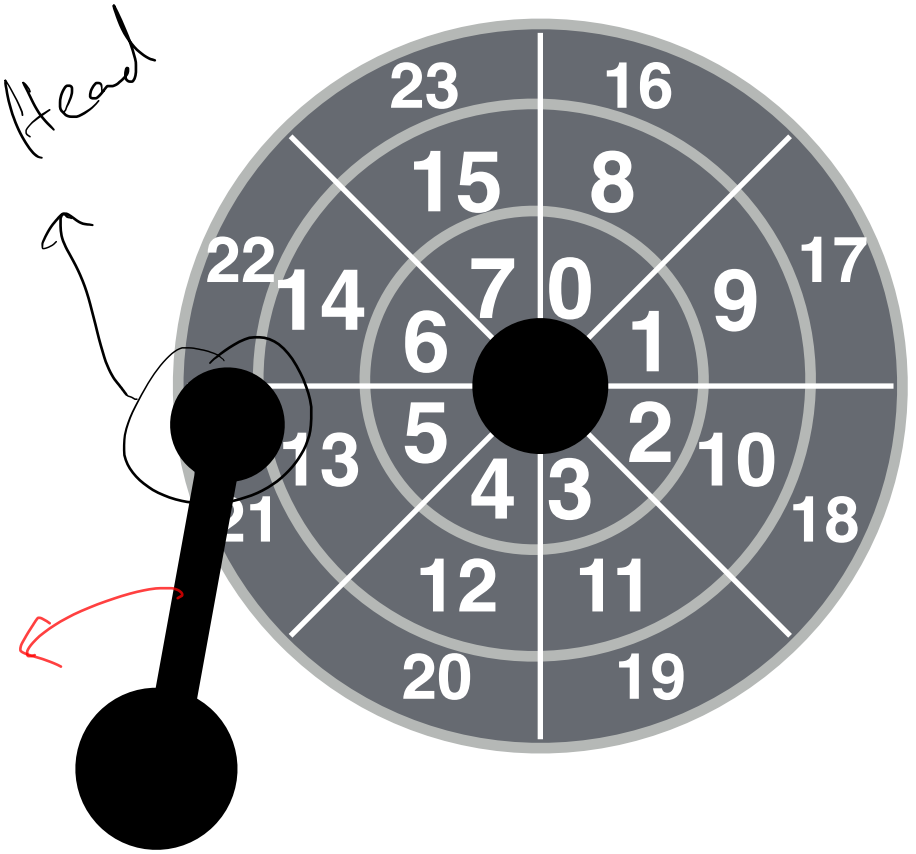


Tracks are divided into numbered sectors

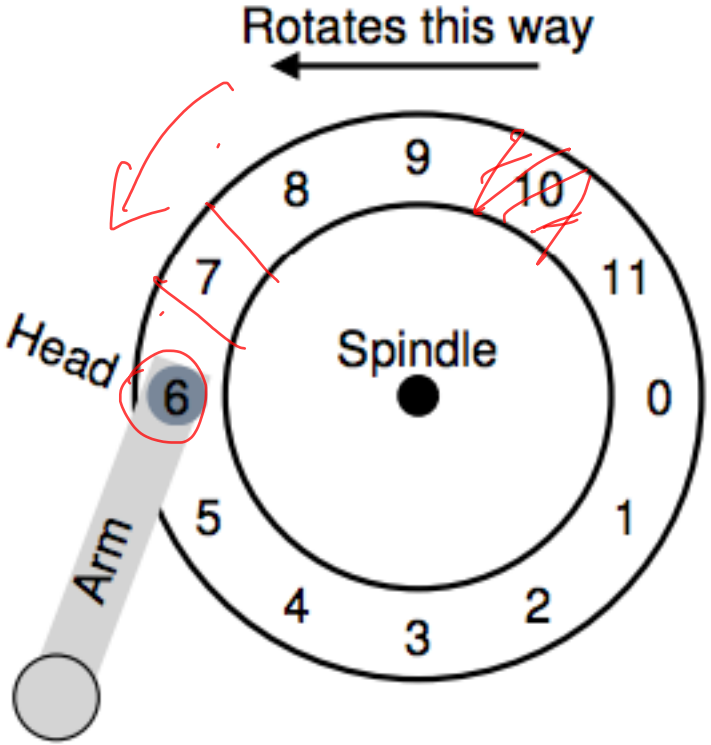




Heads on a moving arm can read from each surface.



READING DATA FROM DISK

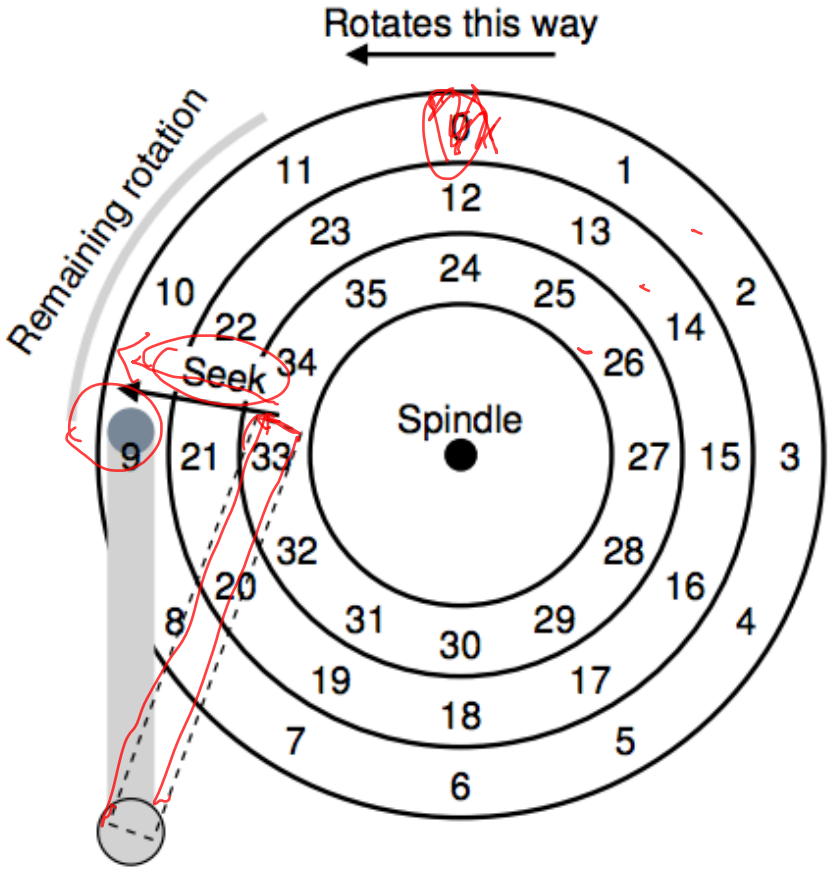


12 sectors in track

Rotational delay

Average wait for half a rotation before sector reaches head

READING DATA FROM DISK



Seek Time

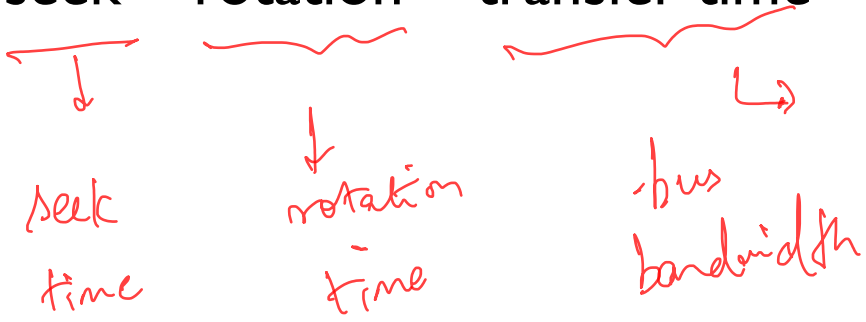
↓

move the disk head to the right track

TIME TO READ/WRITE

Three components:

Time = seek + rotation + transfer time



SEEK, ROTATE, TRANSFER

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?

Pretty fast: depends on RPM and sector density.

100+ MB/s is typical for maximum transfer rate

BUNNY 11

https://tinyurl.com/cs537-sp19-bunny11

tinyurl.com/cs537-sp19-bunny// BUNNY

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

$= T_{seek} + T_{rotation} + T_{transfer}$

Cheetah

$T_{seek} = 4ms$ $T_{rotation} = 2ms$

$T_{transfer} = \frac{4KB}{125\ MB/s} = \frac{4KB}{125 \times 10^3 KB/s}$

$\approx 30\ \mu s = \frac{4 \times 10^{-3}}{125} \frac{1}{s}$

NEXT STEPS

Advanced disk features

Scheduling disk requests

Project 4a: Out tonight

Grades: Project 2b, 3, midterm by tomorrow!