CSCI3150 Introduction to Operating Systems

Lecture 13: File Systems Part I: I/O Devices, HDD

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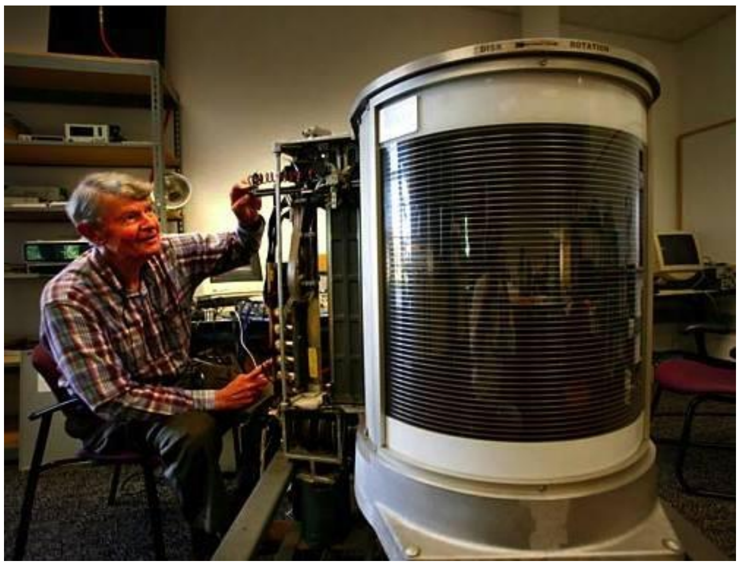
https://github.com/henryhxu/CSCI3150

What problems are we solving?

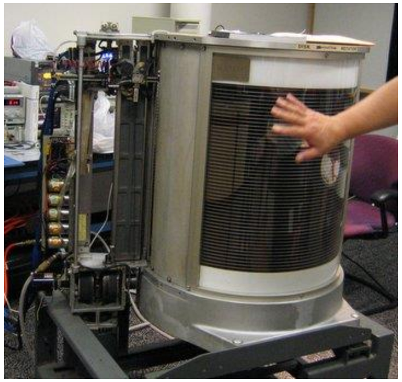
- **Persistent** data storage and access
- Fast-growing industry



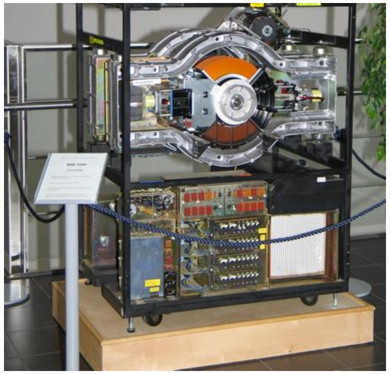
1956, IBM, 24 inches,
3.75MB, 1KB/sec, >$150k

2015, Seagate, 3.5 inches,
5TB, 6GB/sec, <$200

History of storage technology



1956: IBM 350, 24 inches, 3.75MB, 1KB/sec, > $150,000



1980: IBM 3380, first GB disk (1.26G), > $100K

1980: ST-560, first 5.25 inch drive, 5MB, $1500

Tape (DECtape): primary storage for main-frames and mini-computers (1950 ~ 70s)

NextCom notebook 2006: first laptop w/ SSD as storage

History is heavy…

Source: https://en.wikipedia.org/wiki/File:SixHardDriveFormFactors.jpg/

File systems: Agenda

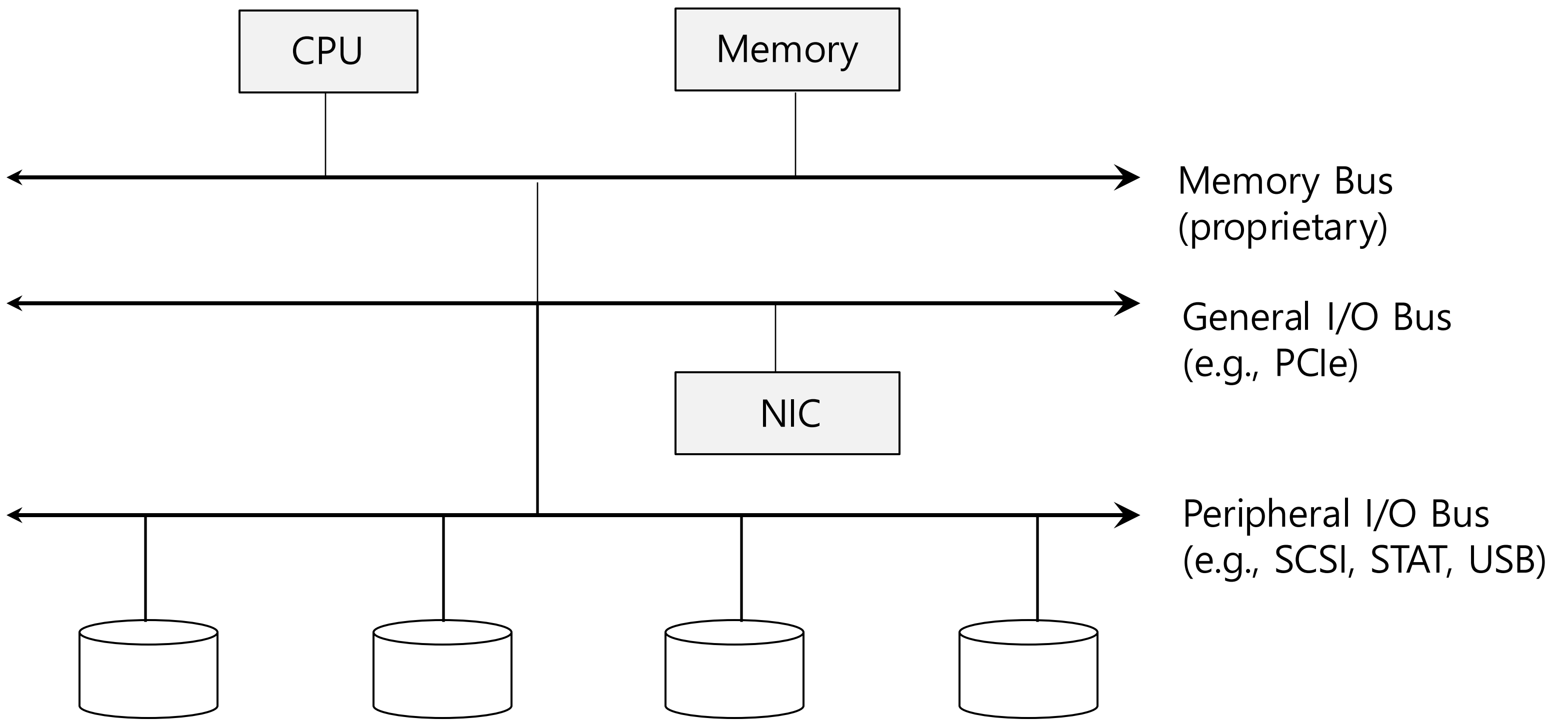
- First we will discuss “generic I/O devices and abstractions”…
- … and properties of physical hard disks
- Then we will discuss how we build file systems on them
  - Files, directories
  - Sharing, protection
  - File system layout, design
  - …

I/O Devices

I/O Devices

- Input/Output, I/O, is **critical** to **interact** with computer systems
- Issues:
  - How should I/O be integrated into systems?
  - What are the general mechanisms?
  - How can we make it efficiently?

Structure I/O Devices



Prototypical System Architecture

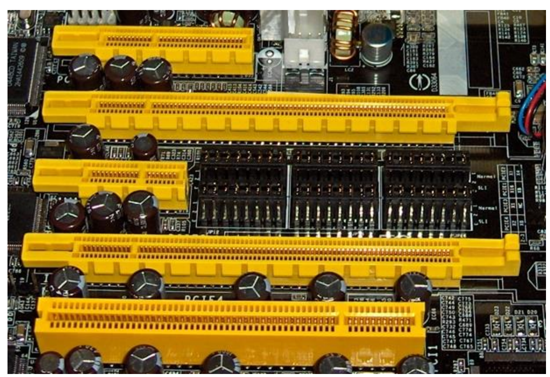
CPU is attached to the main memory of the system via some kind of memory bus.
Some devices are connected to the system via a general I/O bus.

I/O Architecture

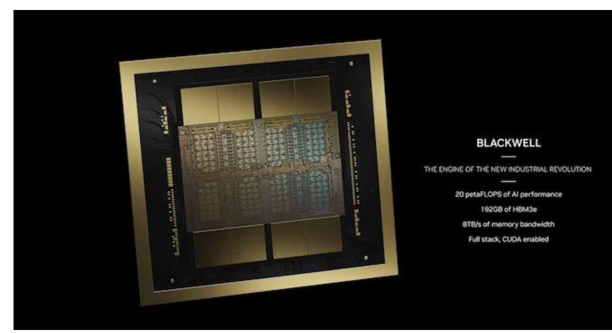
- Buses
  - Data paths to enable information exchange between CPU, RAM, and I/O devices.

- I/O bus
  - Data path that connects a CPU to an I/O device.
  - I/O bus is connected to I/O devices by three hardware components: I/O ports, interfaces and device controllers.

not this bus

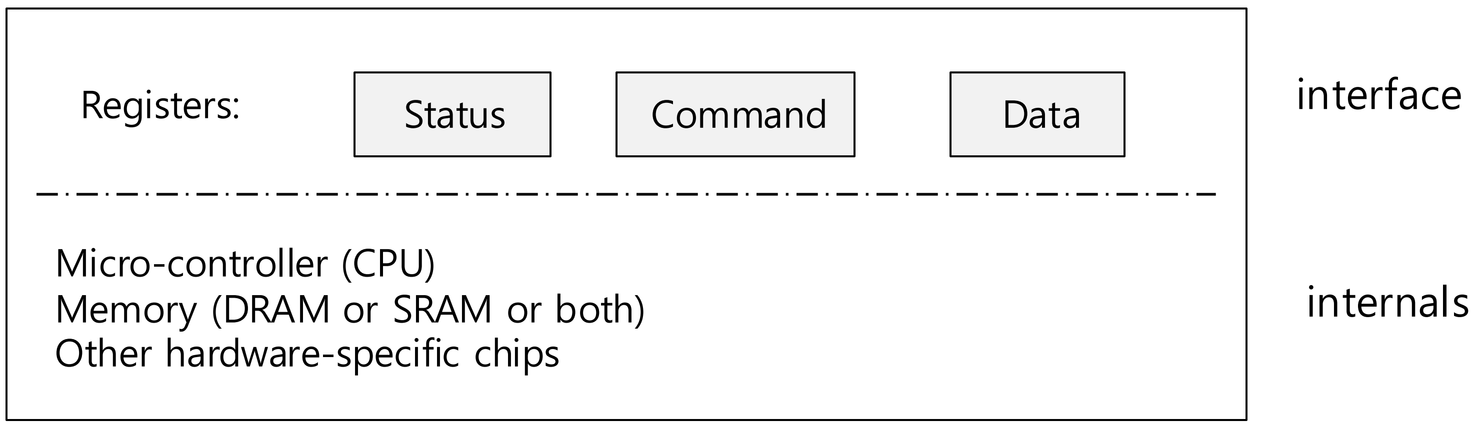


PCIe



Canonical Device

- A Canonical Device has two important components.
  - **Hardware interface** allows the system software to control its operation.
  - **Internals** which are implementation specific.



Canonical Device

Hardware interface of the canonical device

- **status register**
  - See the current status of the device
- **command register**
  - Tell the device to perform a certain task
- **data register**
  - Pass data to the device, or get data from the device

By reading and writing above three registers,
the operating system can control device behavior.

Hardware interface of the canonical device (Cont.)

- Typical interaction

```
while (STATUS == BUSY)
    ; //wait until device is not busy
write data to data register
write command to command register
    (doing so starts the device and executes the command)
while (STATUS == BUSY)
    ; //wait until device is done with your request
```

Polling

- Operating system waits until the device is ready by **repeatedly** reading the status register.
  - Simple; responsive
  - **However, it wastes (lots of!!) CPU time just waiting for the device**
    - Switching to another ready process is better in terms of utilizing the CPU.

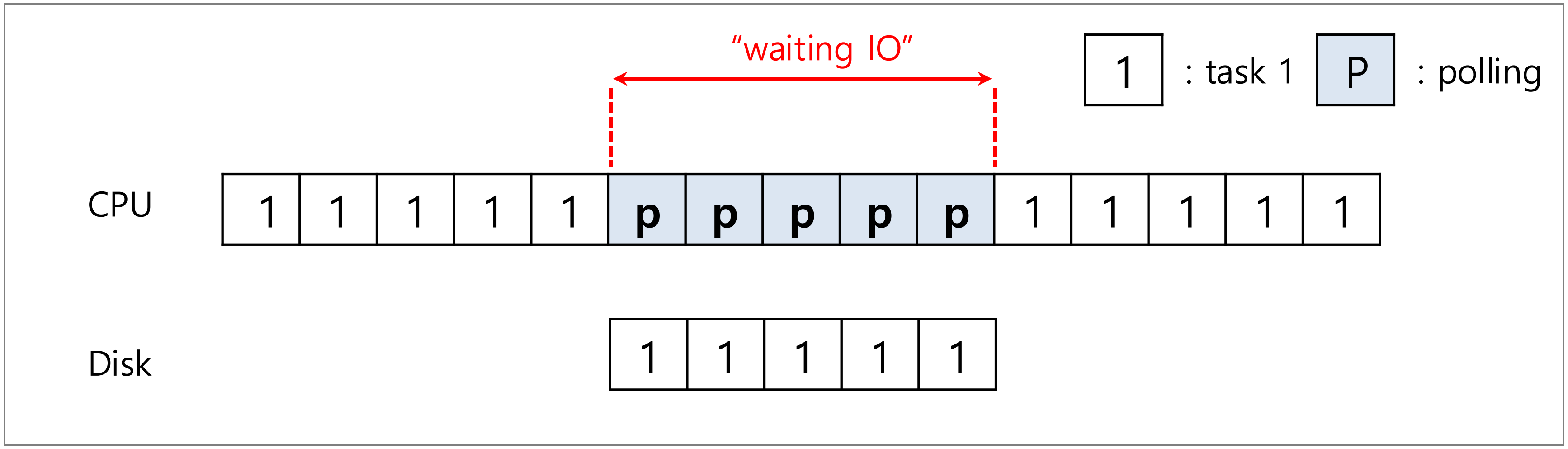


Diagram of CPU utilization with polling

Interrupts

- Put the process waiting on I/O to sleep and context-switch to another
- When the I/O finishes, wake up the sleeping process by **interrupts**
  - Enable **CPU and the disk to be better utilized**

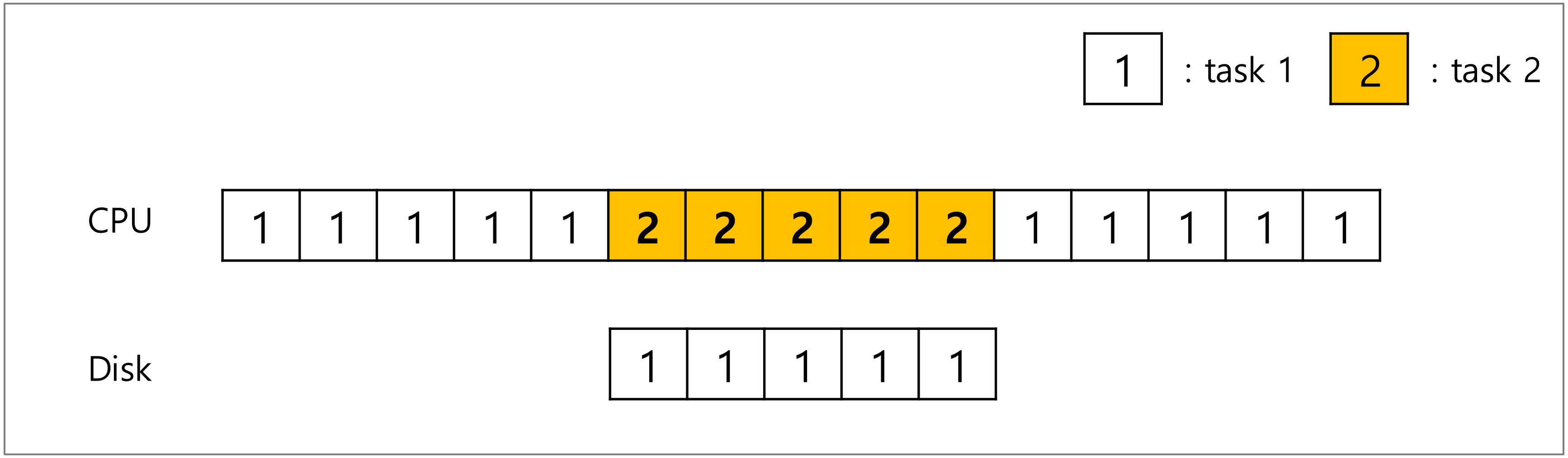


Diagram of CPU utilization with interrupts

Polling vs interrupts

- **Interrupt is not always the best solution**
  - If, device performs very quickly, interrupts will "slow down" the system
  - Because **context switch is expensive (switching to another process)**

If a device is fast → polling is better.
If it is slow → interrupt is better.

CPU is once again over-burdened

- CPU **wastes a lot of time** to copy *a large chunk of data* from memory to the device.

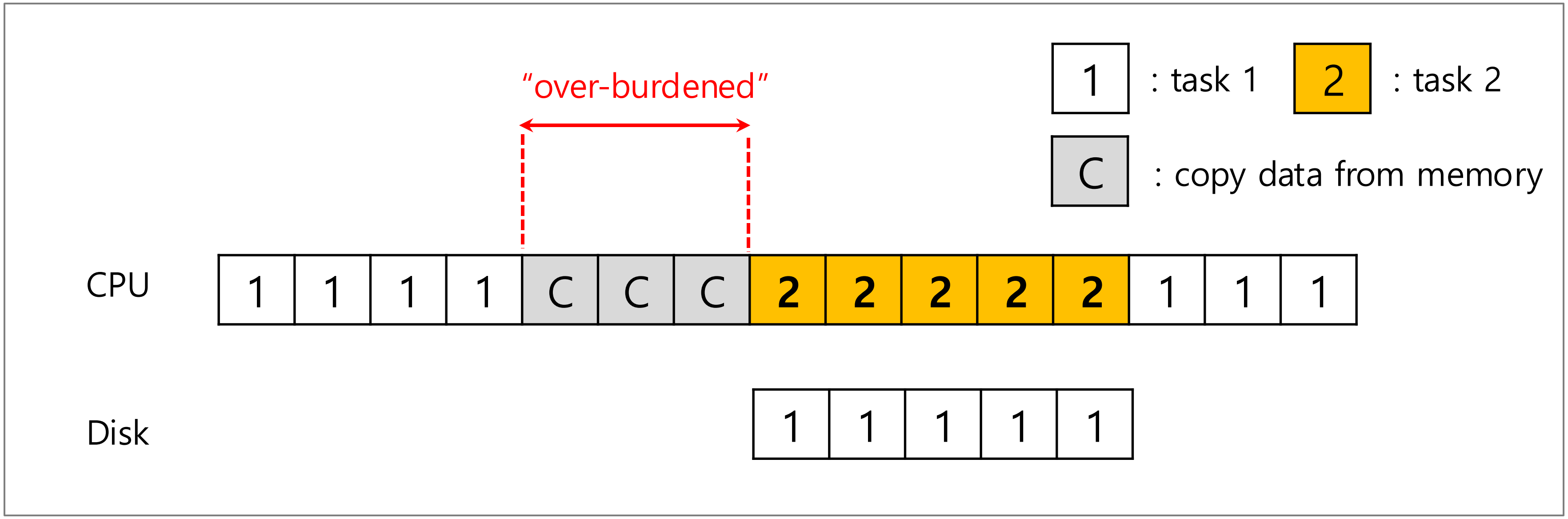


Diagram of CPU utilization

DMA (Direct Memory Access)

- **Copy data** in memory by knowing "where the data lives in memory, how much data to copy"
- When completed, DMA raises an interrupt, I/O begins on disk

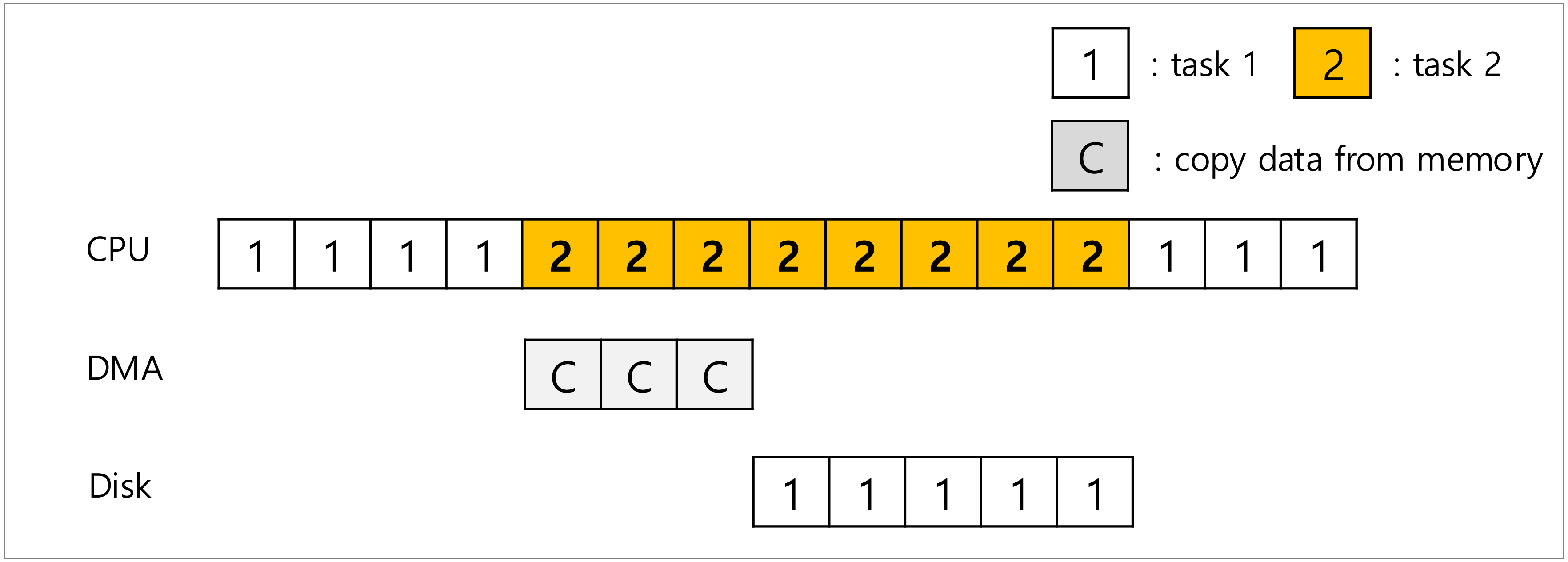


Diagram of CPU utilization by DMA

Device interaction

- How the OS communicates with the **device**?
- Solutions
  - I/O instructions: a way for the OS to send data to specific device registers.
    - `in` and `out` instructions on x86
  - memory-mapped I/O
    - Device registers available as if they were memory locations.
    - The OS `load` (to read) or `store` (to write) to the device instead of main memory.

Device interaction (Cont.)

- How the OS interact with **different types of interfaces**?
  - build a file system that worked on top of SCSI disks, IDE disks, USB keychain drivers, and so on.
- Solution: Abstraction
  - Encapsulate specifics of device interaction

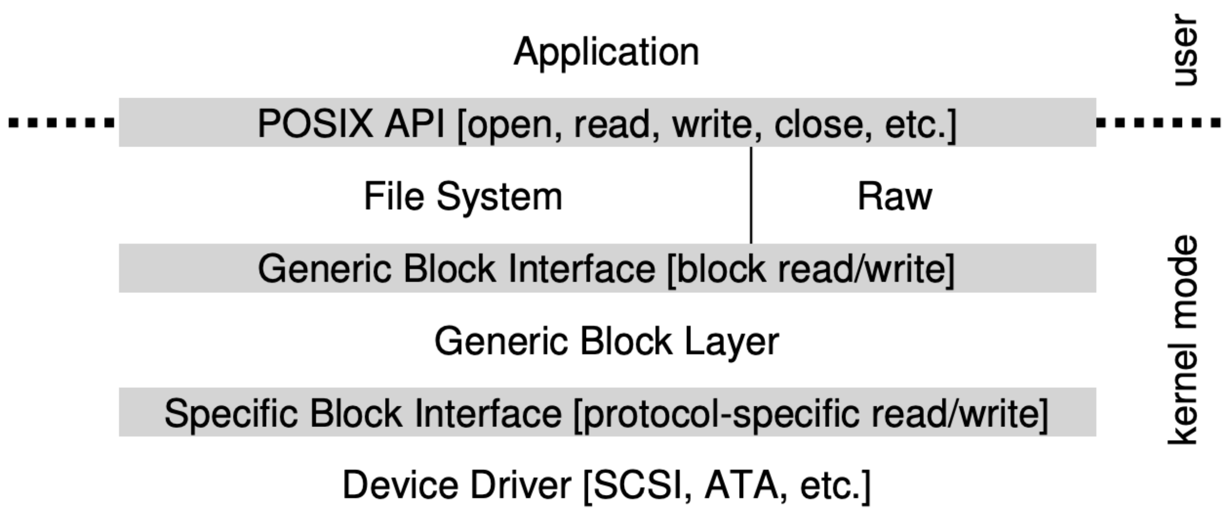


Figure 36.4: **The File System Stack**

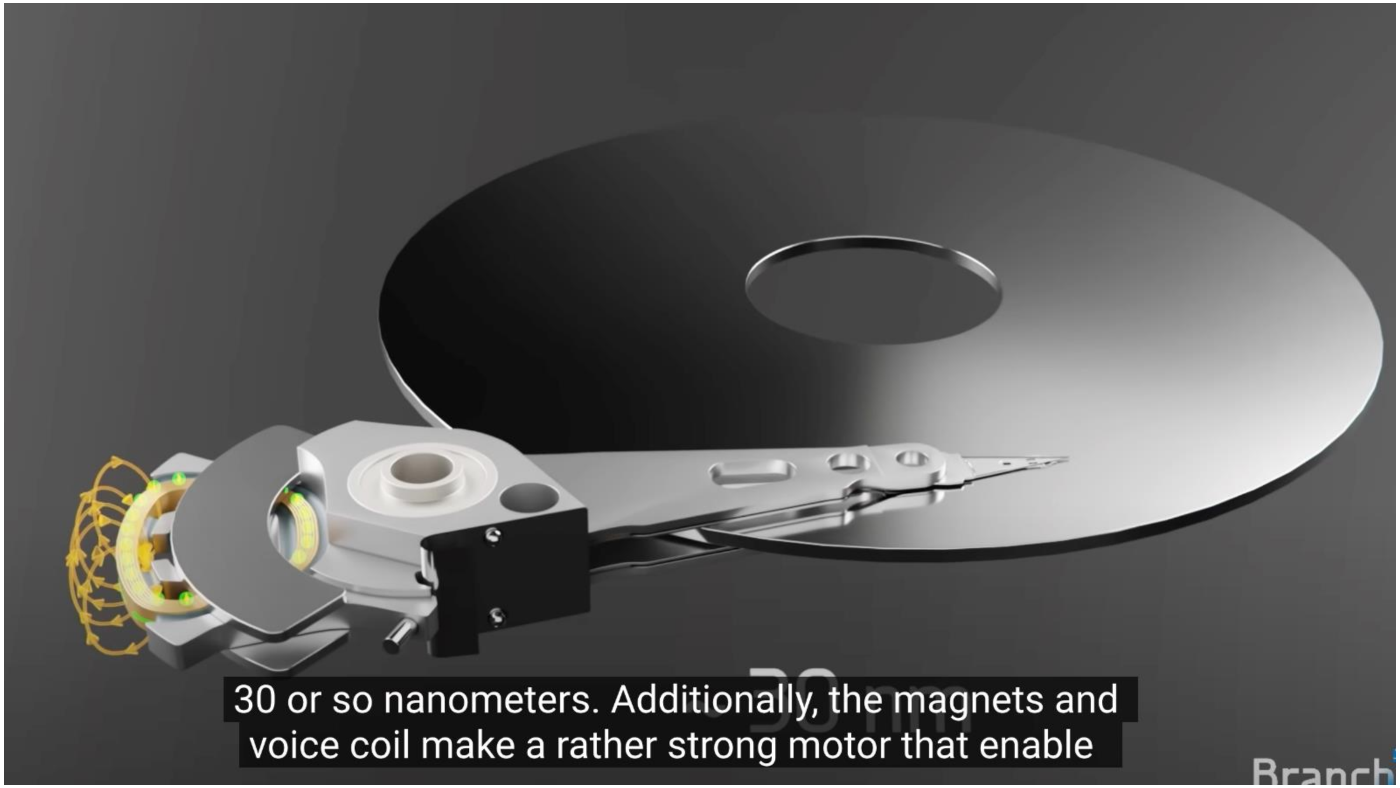
Summary

- To save the CPU cycles for IO
  - Interrupt
  - DMA
- To access the device registers
  - Memory-mapped IO
  - Explicit IO instructions

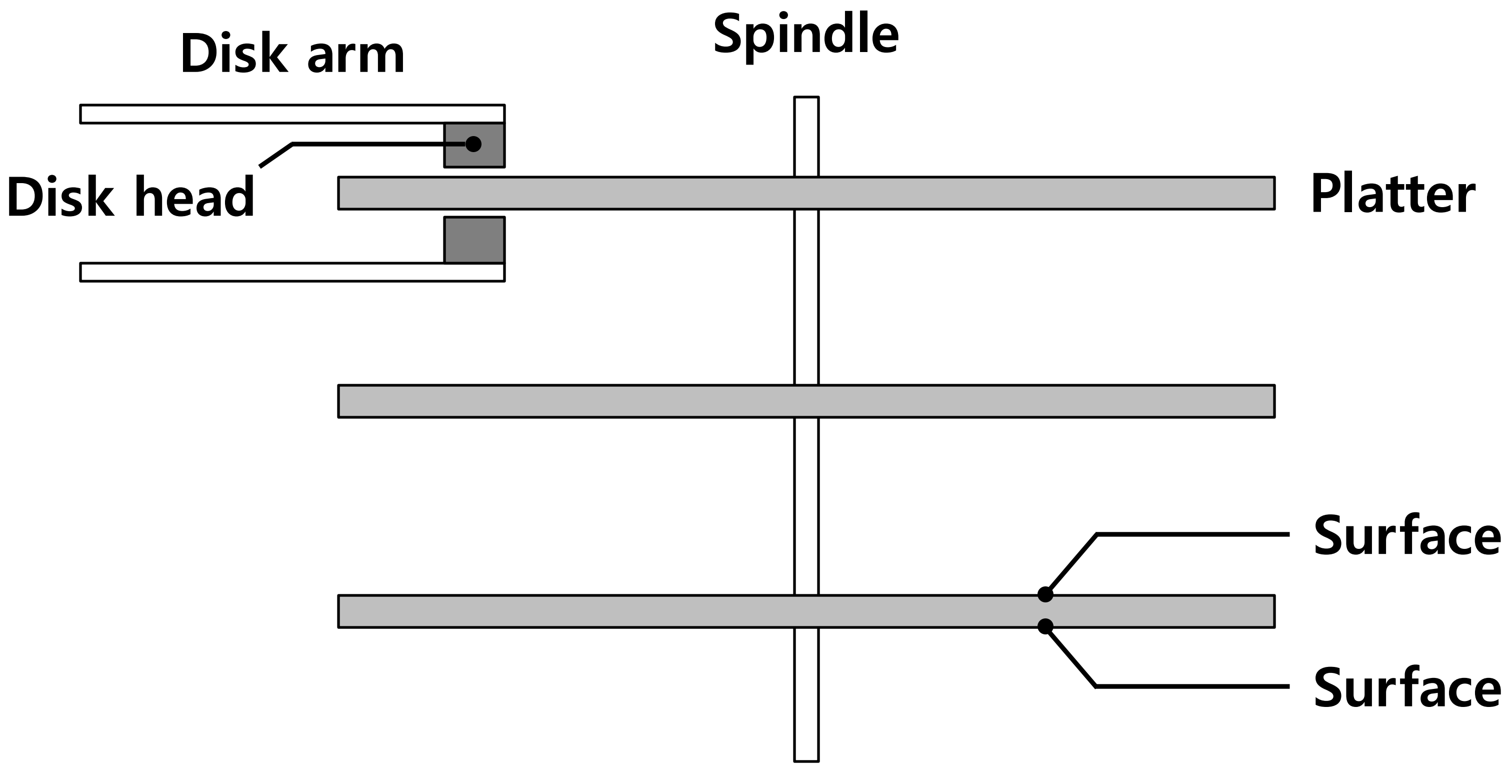
Hard Disk Drive (HDD)

How does it work?

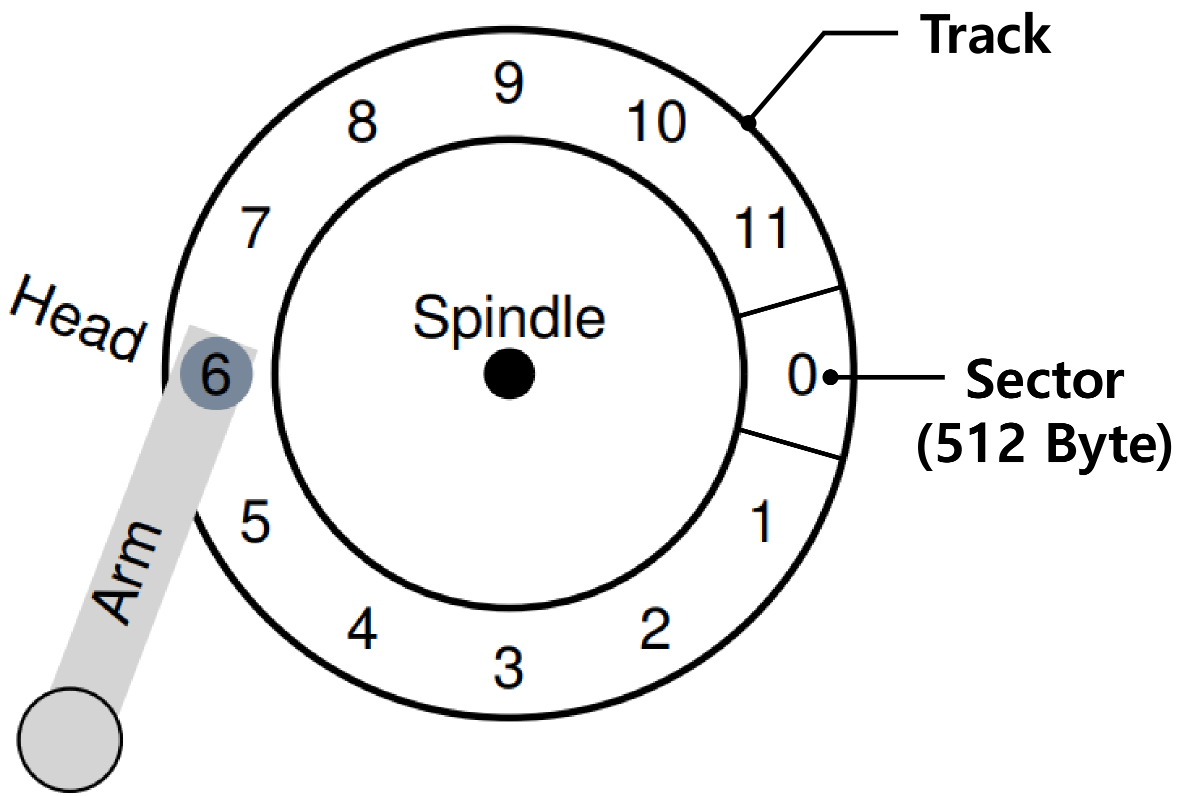
- Physics, electro-magnetic field
- https://www.youtube.com/watch?v=wteUW2sL7bc (physics)
- https://www.youtube.com/watch?v=wtdnatmVdIg (components)



Basic Geometry

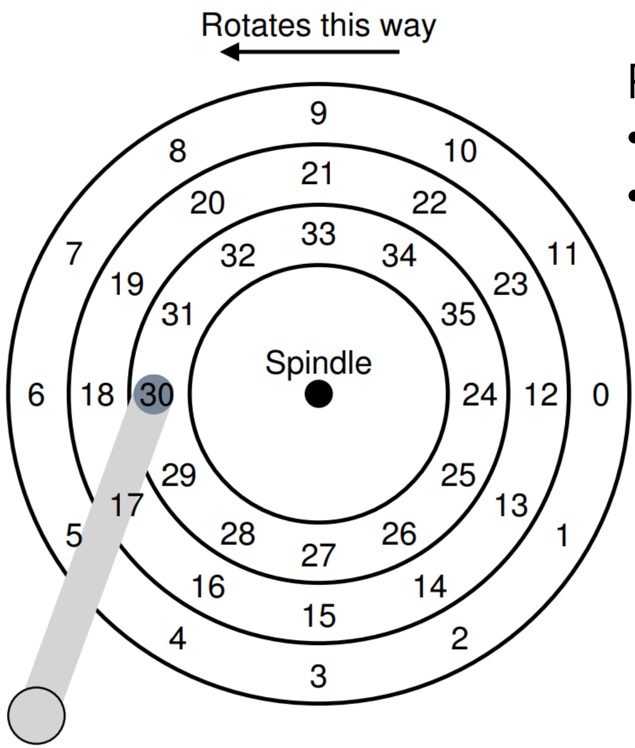


Basic Geometry (Cont.)



A Simple Disk Drive

- Rotation Delay



RPM, rotations per minute

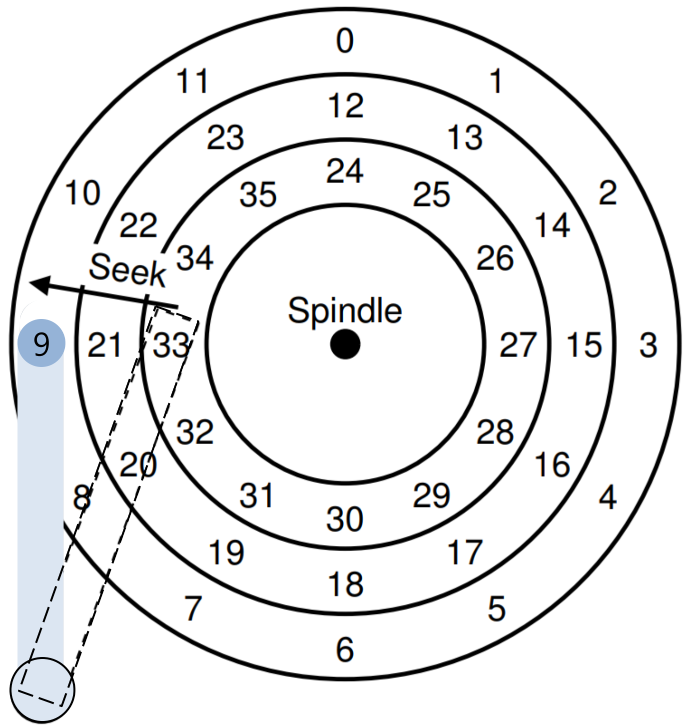
- 7200 to 15000 RPM
- 10000 RPM -> ~6ms per rotation

If the full rotation delay is R,

the rotation delay of (30→24) is $\frac{R}{2}$

A Simple Disk Drive (Cont.)

- Seek Time
  - To read sector 11

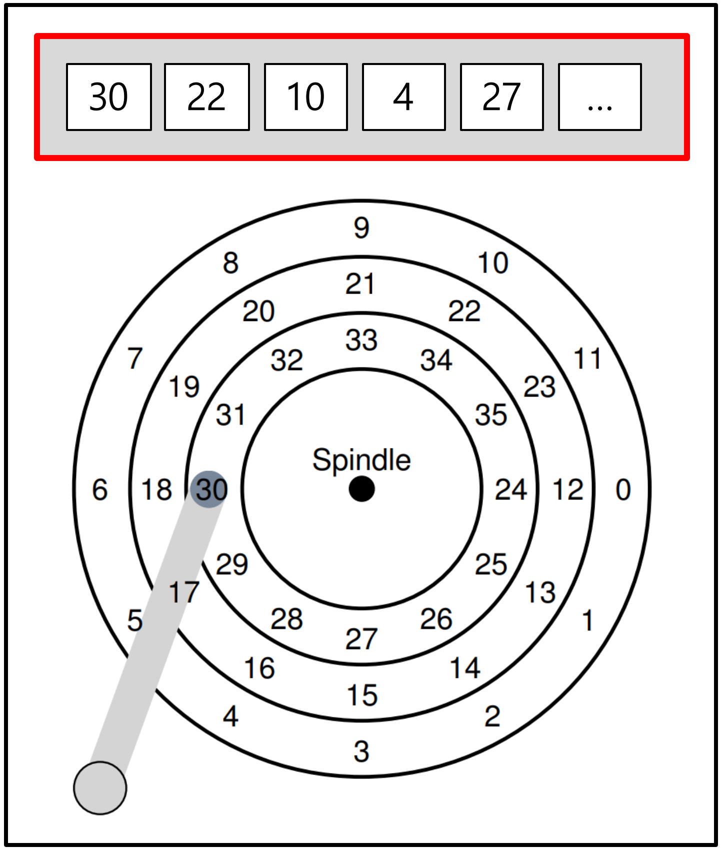


Phases of seek

Acceleration → *Coasting* → *Deceleration* → *Settling time*
(about 0.5~2 ms)

A Simple Disk Drive (Cont.)

- Cache (Track buffer)



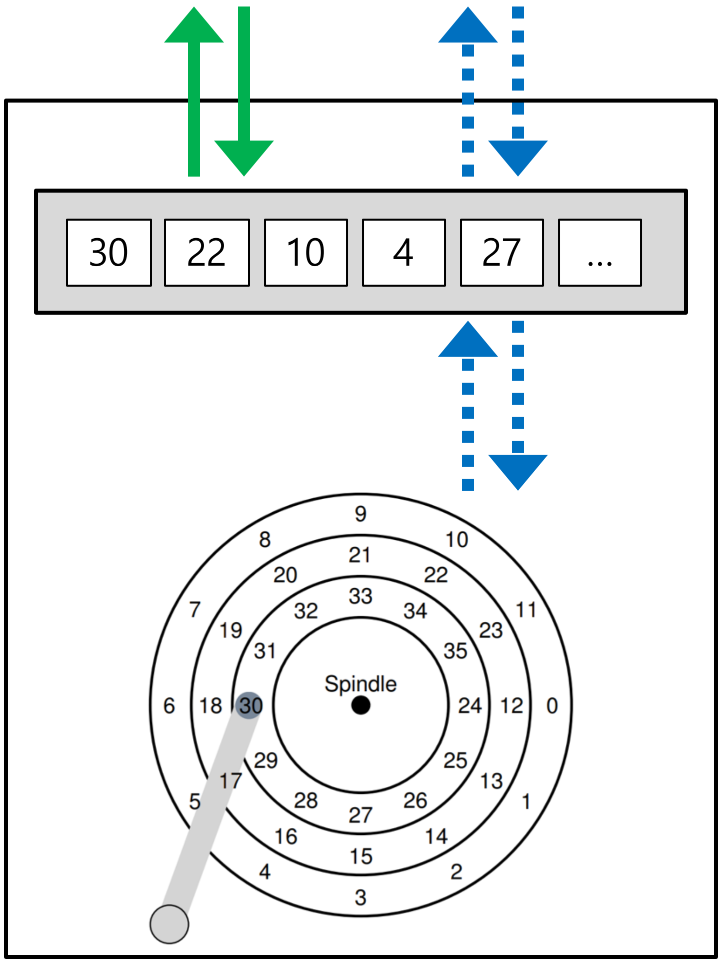
Small amount of memory
(usually around 8 or 16MB)

Hold data read from or written to the disk

Allow the drive to quickly respond to requests

A Simple Disk Drive (Cont.)

- Cache (Track buffer)



Write-Back

Acknowledge the write has completed when it has put the data in its memory

Write-Through

Acknowledge after the write has actually been written to disk

I/O Time: Doing The Math

- I/O Time

$$T_{I/O} = T_{seek} + T_{rotation} + T_{transfer}$$

- I/O Rate

$$R_{I/O} = \frac{Size_{Transfer}}{T_{I/O}}$$

I/O Time: Doing The Math (Cont.)

- 4KB Random Write Example

	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} = 4ms

$T_{rotation}$ = 15,000 RPM(= 250RPS = 4ms / 1 rotation) / 2
= 2ms

$T_{transfer}$ = 4KB / 125(MB/s)
= 30us

$T_{I/O}$ = 4ms + 2ms + 30us ≒ 6ms

$R_{I/O}$ = 4KB / 6ms = 0.66MB/s

I/O Time: Doing The Math (Cont.)

- 4KB Random Write Example (Cont.)

	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} = 9ms

$T_{rotation}$ = 7,200 RPM(= 120RPS = 8ms / 1 rotation) / 2
= 4ms

$T_{transfer}$ = 4KB / 105(MB/s)
= 38us

$T_{I/O}$ = 9ms + 4ms + 38us ≒ 13ms

$R_{I/O}$ = 4KB / 13ms = 0.31MB/s

I/O Time: Doing The Math (Cont.)

- Sequential Write Example

	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} = 4ms

$T_{rotation}$ = 15,000 RPM(= 250RPS = 4ms / 1 rotation) / 2
= 2ms

$T_{transfer}$ = 100MB / 125(MB/s)
= 800ms

$T_{I/O}$ = 4ms + 2ms + 800ms = 806ms ≒ 800ms

$R_{I/O}$ = 100MB / 800ms = 125MB/s

I/O Time: Doing The Math (Cont.)

- Sequential Write Example (Cont.)

	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} = 9ms

$T_{rotation}$ = 7,200 RPM(= 120RPS = 8ms / 1 rotation) / 2
= 4ms

$T_{transfer}$ = 100MB / 105(MB/s)
= 950ms

$T_{I/O}$ = 9ms + 4ms + 950ms = 963ms ≒ 950ms

$R_{I/O}$ = 100MB / 950ms = 105MB/s

I/O Time: Doing The Math (Cont.)

	Cheetah	Barracuda
$R_{I/O}$ Random	0.66 MB/s	0.31 MB/s
$R_{I/O}$ Sequential	125 MB/s	105 MB/s

Performance vs Capacity

	Cheetah	Barracuda
$R_{I/O}$ Random	0.66 MB/s	0.31 MB/s
$R_{I/O}$ Sequential	125 MB/s	105 MB/s

Random Write vs Sequential Write