BITS Pilani
Pilani Campus

Computer Organization and Software Systems

CONTACT SESSION 2

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Today's Class

Contact Hour	List of Topic Title	Text/Ref Book/external resource
3	**Performance Assessment** MIPS Rate Amdahl's Law	Class Slides
4	**Memory Organization** Storage Technologies Random Access Memory Disk Storage Solid State Disks Storage Technology Trends	T1, R2

Performance Assessment

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Units

- Kilo- (K) = 1 thousand = 10^3 and 2^{10}
- Mega- (M) = 1 million = 10^6 and 2^{20}
- Giga- (G) = 1 billion = 10^9 and 2^{30}
- Tera- (T) = 1 trillion = 10^{12} and 2^{40}
- Peta- (P) = 1 quadrillion = 10^{15} and 2^{50}
- Exa – (E) = 1 quintillion = 10^{18} and 2^{60}

Byte = a unit of storage

- 1KB = 2^{10} = 1024 Bytes
- 1MB = 2^{20} = 1,048,576 Bytes
- Main memory (RAM) is measured in MB / GB
- Disk storage is measured in GB for small systems, TB for large systems.

Examples

Hertz = clock cycles per second (frequency)

- 1MHz = 1,000,000Hz
- Processor speeds are measured in MHz or GHz.

Units…

- Milli- (m) = 1 thousandth = 10^{-3}
- Micro- (μ) = 1 millionth = 10^{-6}
- Nano- (n) = 1 billionth = 10^{-9}
- Pico- (p) = 1 trillionth = 10^{-12}
- Femto- (f) = 1 quadrillionth = 10^{-15}

Examples

- Millisecond = 1 thousandth of a second
  - Hard disk drive access times are often 10 to 20 milliseconds.
- Nanosecond = 1 billionth of a second
  - Main memory access times are often 50 to 70 nanoseconds.
- Micron (micrometer) = 1 millionth of a meter
  - Circuits on computer chips are measured in microns.

Important Terms

- **Execution time** : The total time required for the computer to complete a task, including disk accesses, memory accesses, I/O activities, operating system overhead, CPU execution
- **Throughput or bandwidth** :number of tasks completed per unit time.

Example

Do the following changes to a computer system, increase throughput, decrease execution time, or both?

1. Replacing the processor in a computer with a faster version
2. Adding additional processors of same type to a system, that is, it uses multiple processors for separate tasks

Contd…

- Relationship between Performance and execution time of Computer X

$$\text{Performance}_X = \frac{1}{\text{Execution time}_X}$$

- if the performance of X is greater than the performance of Y, we have

$$\text{Performance}_X > \text{Performance}_Y$$

$$\frac{1}{\text{Execution time}_X} > \frac{1}{\text{Execution time}_Y}$$

$$\text{Execution time}_Y > \text{Execution time}_X$$

Contd…

- Quantitative performance analysis
  - Computer X is “n” times faster than Computer Y

$$\frac{\text{Performance}_X}{\text{Performance}_Y} = n$$

$$\frac{\text{Performance}_X}{\text{Performance}_Y} = \frac{\text{Execution time}_Y}{\text{Execution time}_X} = n$$

- If performance of X is *n* times better than Y, then the execution time on Y is *n* times longer than it is on X

Example

- If computer A runs a program in 10 seconds and computer B runs the same program in 15 seconds, how much faster is A than B?

$$\frac{\text{Performance}_A}{\text{Performance}_B} = \frac{\text{Execution time}_B}{\text{Execution time}_A} = n$$

- Computer A is therefore 1.5 times faster than B.

CPU performance and its factors

$$\frac{\text{Performance}_X}{\text{Performance}_Y} = \frac{\text{Execution time}_Y}{\text{Execution time}_X} = n$$

- CPU execution time for a program:

$$\begin{matrix}\text{CPU execution time} \\ \text{for a program}\end{matrix} = \begin{matrix}\text{CPU clock cycles} \\ \text{for a program}\end{matrix} \times \text{Clock cycle time}$$

$$\begin{matrix}\text{CPU execution time} \\ \text{for a program}\end{matrix} = \frac{\text{CPU clock cycles for a program}}{\text{Clock rate}}$$

Example

- Our favorite program runs in 10 seconds on computer A, which has a 2 GHz clock. We are trying to help a computer designer build a computer, B, which will run this program in 6 seconds. The designer has determined that a substantial increase in the clock rate is possible, but this increase will affect the rest of the CPU design, causing computer B to require 1.2 times as many clock cycles as computer A for this program. What clock rate should we tell the designer to target?

$$\begin{array}{c}\text{CPU execution time}\\ \text{for a program}\end{array} = \frac{\text{CPU clock cycles for a program}}{\text{Clock rate}}$$

Computer A

Execution TimeA = 10s

Clock RateA = 2×10^9 Hz

CPU Clock CycleA = ?

Computer B

Execution TimeB = 6s

CPU Clock CyclesB = 1.2xClock CycleA

Clock Rate B = ?

Instruction Performance

- CPI: Clock cycles Per Instruction
  - Average number of clock cycles per instruction for a program or program fragment.

$$\text{CPU clock cycles} = \text{Instructions for a program} \times \begin{array}{c}\text{Average clock cycles}\\ \text{per instruction}\end{array}$$

Example

Computer A has a clock cycle time of 250 ps and a CPI of 2.0 for some program, and computer B has a clock cycle time of 500 ps and a CPI of 1.2 for the same program. Which computer is faster for this program and by how much?

Solution

Computer A has a clock cycle time of 250 ps and a CPI of 2.0 for some program, and computer B has a clock cycle time of 500 ps and a CPI of 1.2 for the same program. Which computer is faster for this program and by how much?

- the number of processor clock cycles for each computer

  $\text{CPU clock cycles}_A = I \times 2.0$

  $\text{CPU clock cycles}_B = I \times 1.2$

- Execution time for each computer

  $\text{Execution time} = \text{CPU clock cycles} \times \text{Clock cycle time}$

  $\text{Execution time}_A = I \times 2.0 \times 250 \text{ ps} = 500 \times I \text{ ps}$

  $\text{Execution time}_B = I \times 1.2 \times 500 \text{ ps} = 600 \times I \text{ ps}$

- Comparison:

$$\frac{\text{CPU performance}_A}{\text{CPU performance}_B} = \frac{\text{Execution time}_B}{\text{Execution time}_A} = \frac{600\, I \text{ ps}}{500\, I \text{ ps}} = 1.2$$

Amdahl's Law

- proposed by Gene Amdahl in 1967
- deals with the potential speedup of a program using multiple processors compared to a single processor

$$\text{Speedup} = \frac{\text{Performance after enhancement}}{\text{Performance before enhancement}} = \frac{\text{Execution time before enhancement}}{\text{Execution time after enhancement}}$$

Break 5 Min

Amdahl's Law

$$\text{Speedup} = \frac{\text{Performance after enhancement}}{\text{Performance before enhancement}} = \frac{\text{Execution time before enhancement}}{\text{Execution time after enhancement}}$$

$$S = \frac{1}{(1-f) + \frac{f}{k}}$$

S=Speedup,
f=fraction of time enhancement,
k=speedup of the faster component

Amdahl's Law

If 90% of a program is speeded up to run 10 times faster f=0.9 and k=10

Overall speedup is 1/(1-0.9)+(0.9/10)=

1/(0.1+0.09)=1/(0.19)=5.26

Making 80% of a program run 20% faster

f=0.80 and k=1.2

1/(1-0.8)+(0.8/1.2)=

1/(0.2+0.8/1.2)=1/(0.2+0.66)=1/0.866=1.154

Example

On a large system CPU upgrade makes it faster by 50% for INR 10,000. A disk drive upgrade of INR 7000 speeds it up by 150%. Evaluate the speedups? Processes spend 70% in CPU and 30% waiting Disk drives.

Processor upgrade

$f = 0.70,\quad k = 1.5 \qquad S = \dfrac{1}{(1 - 0.7) + 0.7/1.5}$ **=1.304**

30% improvement

Disk Drive upgrade

$f = 0.30,\quad k = 2.5 \qquad S = \dfrac{1}{(1 - 0.3) + 0.3/2.5}$ **=1.219**

22% Improvement

CPU-30 % improvement -faster by 50%
---so 1% increment is INR 10000/30=INR 333

DISK DRIVE- 22% improvement – speeds up 150%---so a 1% increment is INR 7000/22=INR=318

Each 1% of improvement for the processor costs INR333, and for the disk a 1% improvement costs INR318. "Is cost/performance the most important metric?"

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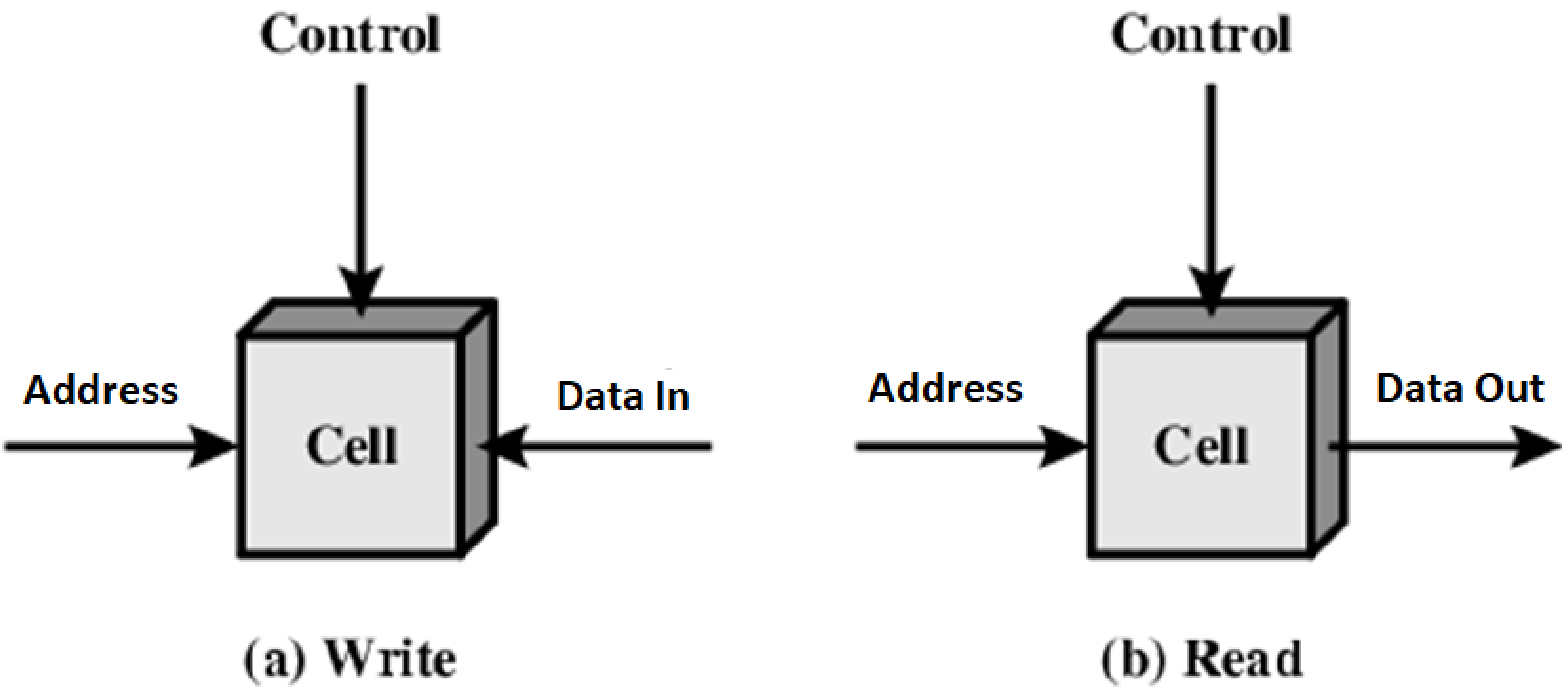
Memory Organization

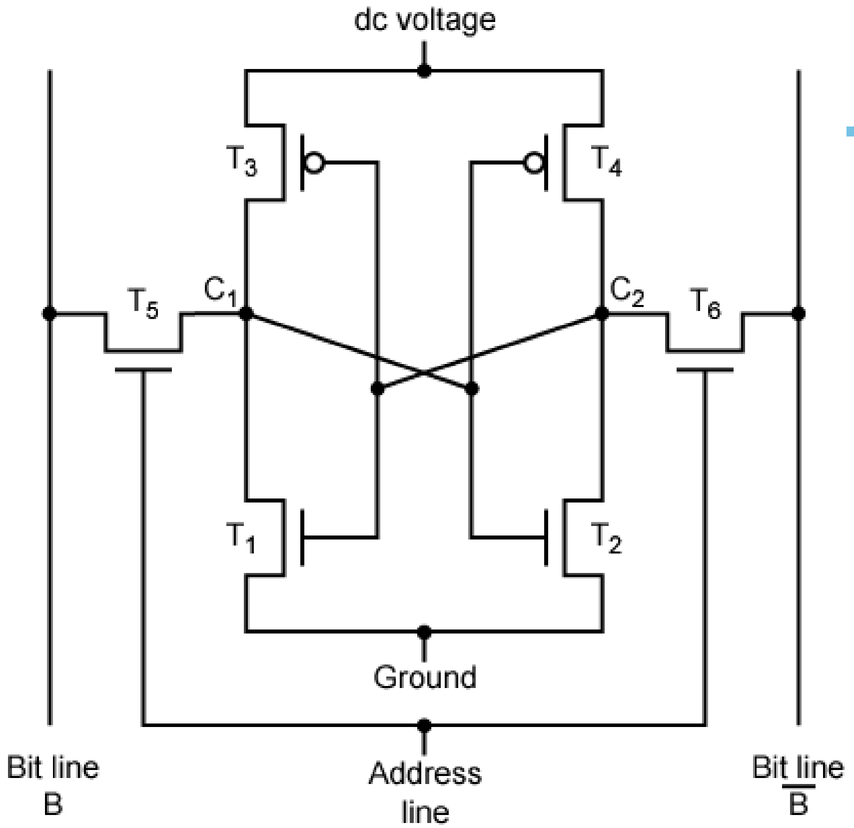
Semiconductor Memory

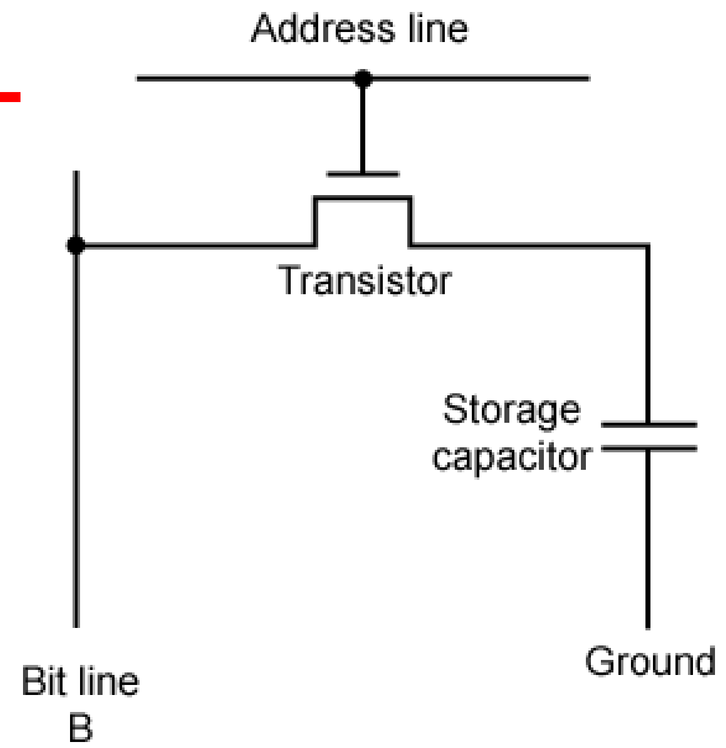


Random-Access Memory (RAM)

- Key features
  - RAM is traditionally packaged as a chip.
  - Basic storage unit is normally a cell (one bit per cell).
  - Multiple RAM chips form a memory.
- RAM comes in two varieties:
  - SRAM (Static RAM)
  - DRAM (Dynamic RAM)
- SRAM and DRAM are volatile memories
  - Lose information if powered off.

SRAM vs DRAM Summary





	Trans. per bit	Access time	Needs refresh?	Needs EDC?	Cost	Applications
SRAM	4 to 6	1X	No	Maybe	100x	Cache
DRAM	1	10X	Yes	Yes	1X	Main memories, frame buffers

Read Only Memory

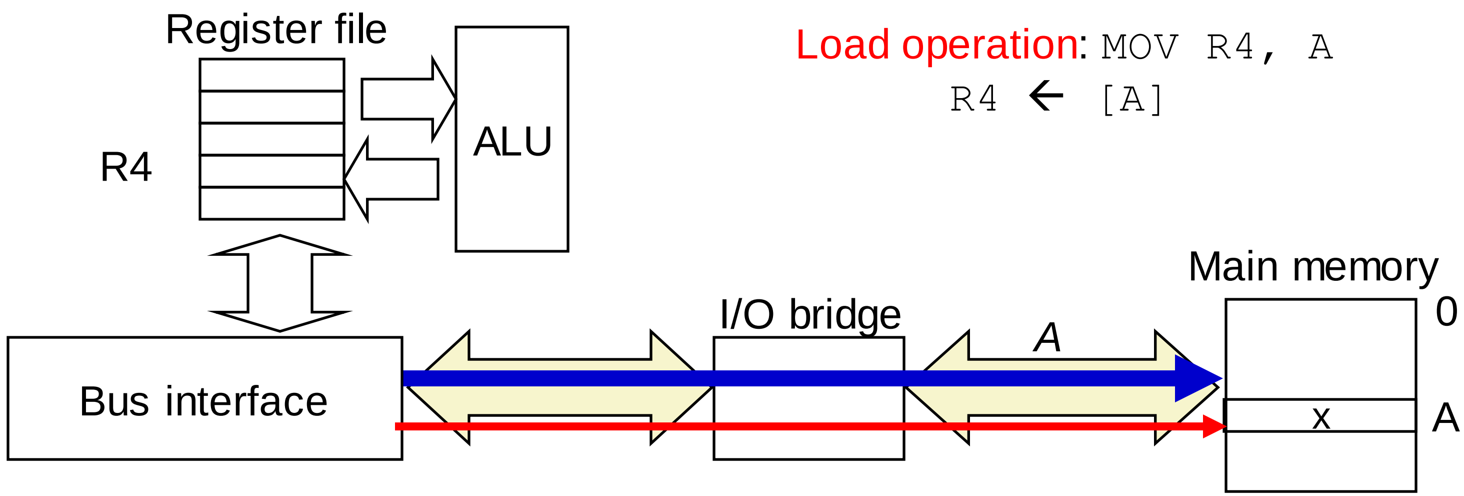
- Permanent Storage and Nonvolatile Memories
- Read Only Memory Variants:
  - Read-only memory (ROM): programmed during production
  - Programmable ROM (PROM): can be programmed once
  - Erasable PROM (EPROM): can be bulk erased (UV, X-Ray)
  - Electrically erasable PROM (EEPROM): electronic erase capability
  - Flash memory: EEPROMs. with partial (block-level) erase capability
    - Wears out after about 100,000 erasing
- Firmware

Applications

- Storing fonts for printers
- Storing sound data in musical instruments
- Video game consoles
- Implantable Medical devices.
- High definition Multimedia Interfaces(HDMI)
- BIOS chip in computer
- Program storage chip in modem, video card and many electronic gadgets, controllers for disks, network cards, ….

Memory Read Operation (1)

CPU places address *A* and then read control signal on the memory bus



Load operation: `MOV R4, A`

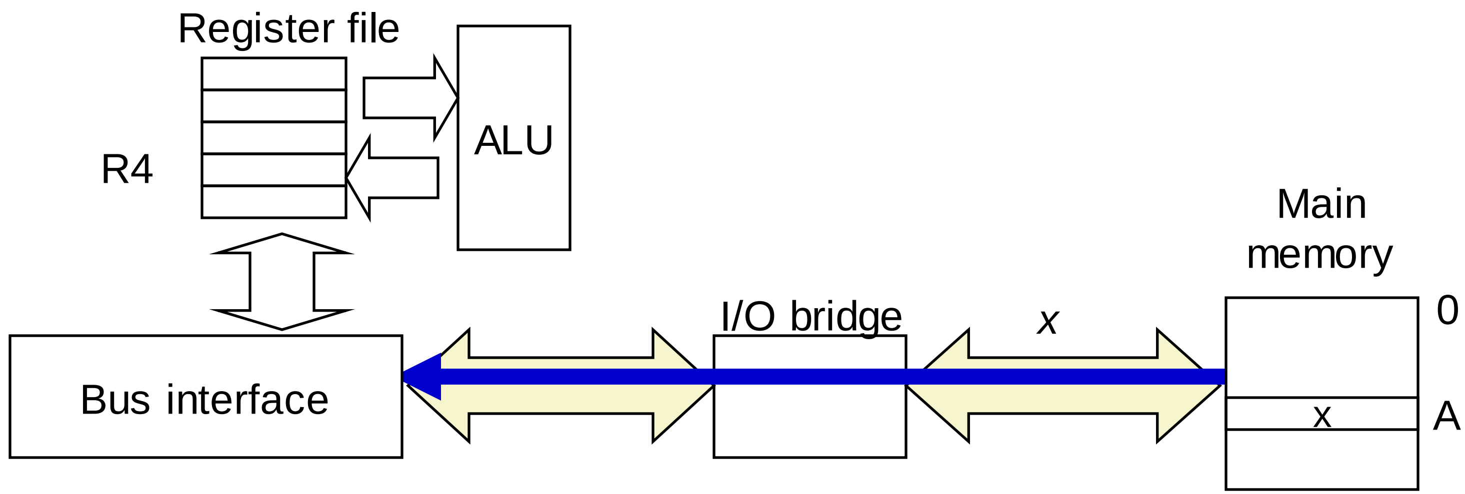
`R4 ← [A]`

Memory Read Operation (2)

Main memory reads A from the memory bus, retrieves word x, and places it on the bus

Load operation: `MOV R4, A`

`R4 ← [A]`

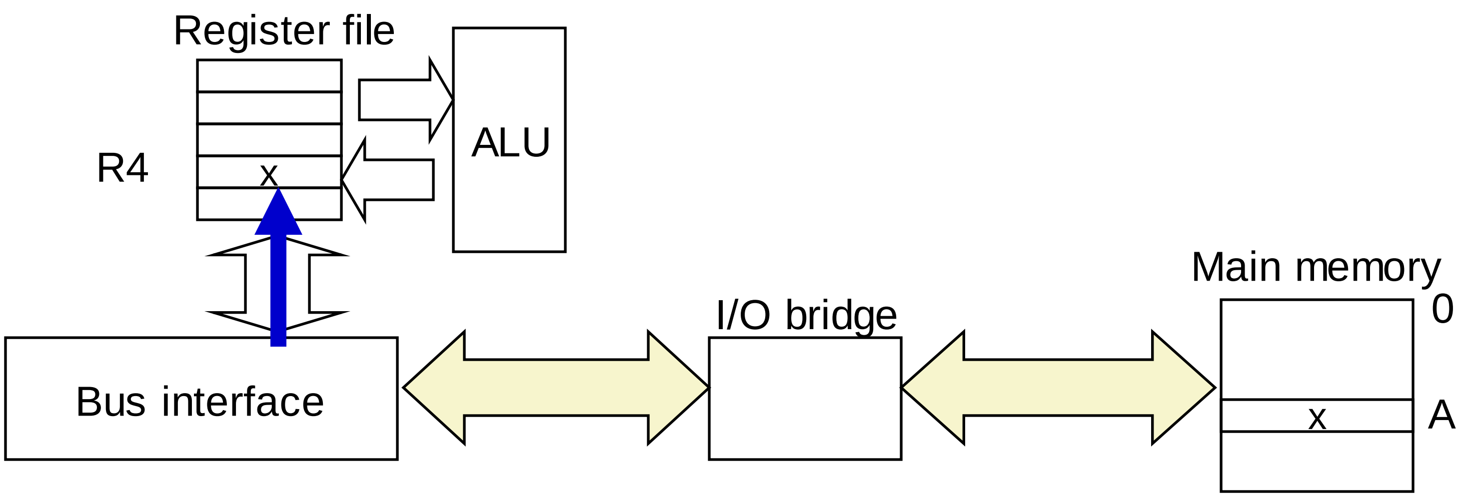


Memory Read Operation (3)

CPU read word x from the bus and copies it into register R4.

Load operation: `MOV R4, A`

`R4 ←[A]`

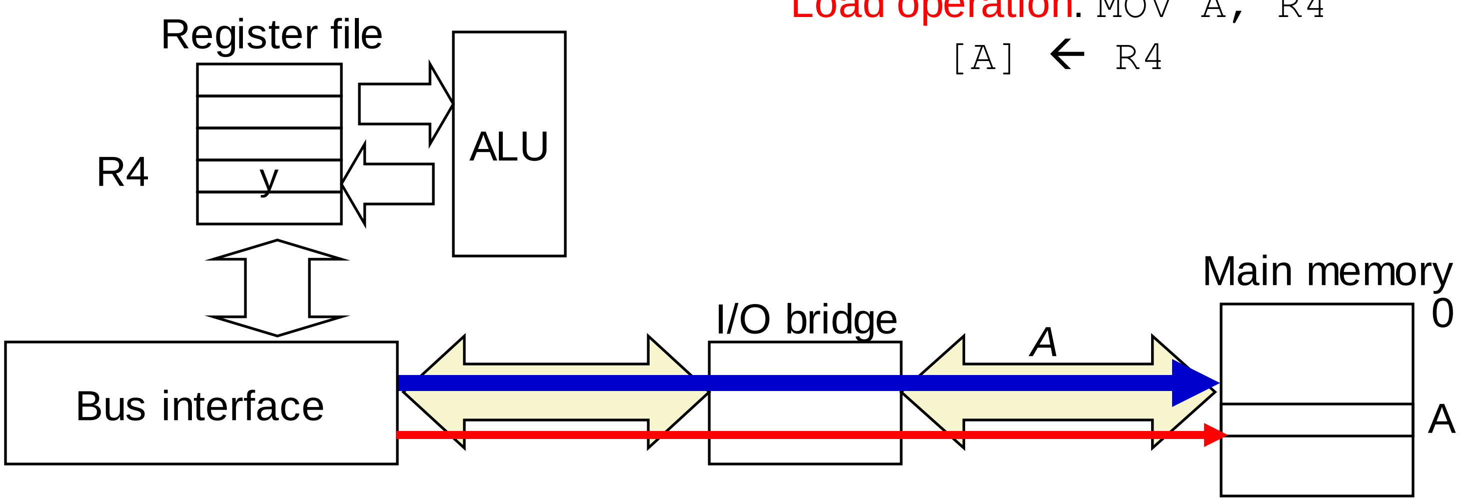


Memory Write Operation (1)

CPU places address *A* and WRITE control signal on bus. Main memory reads them and waits for the corresponding data word to arrive.

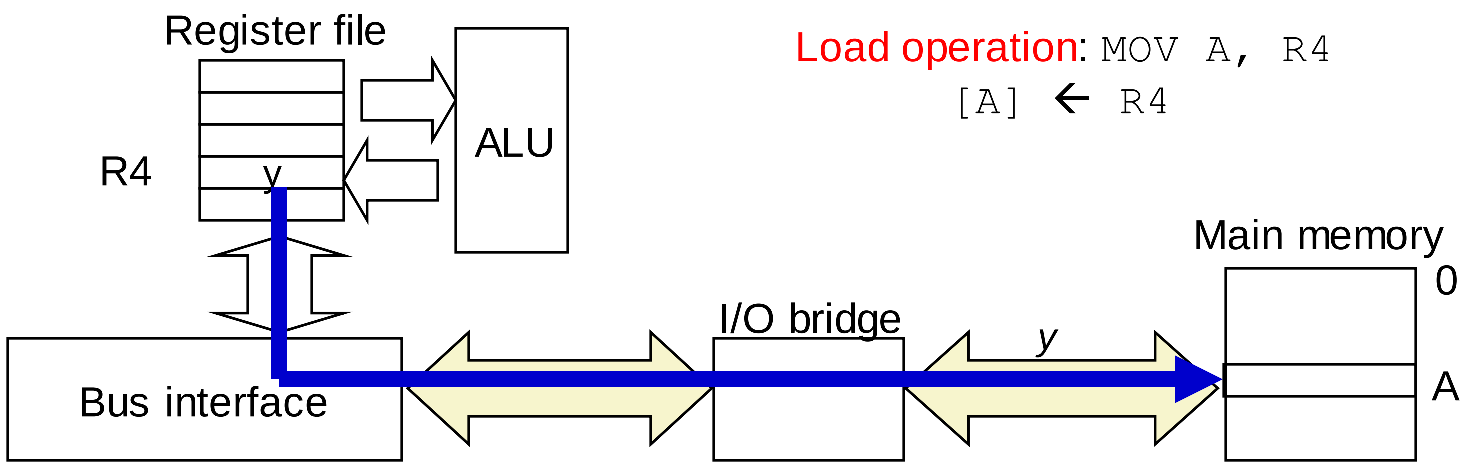
Load operation: `MOV A, R4`

`[A] ← R4`



Memory Write Operation (2)

CPU places data word y on the bus

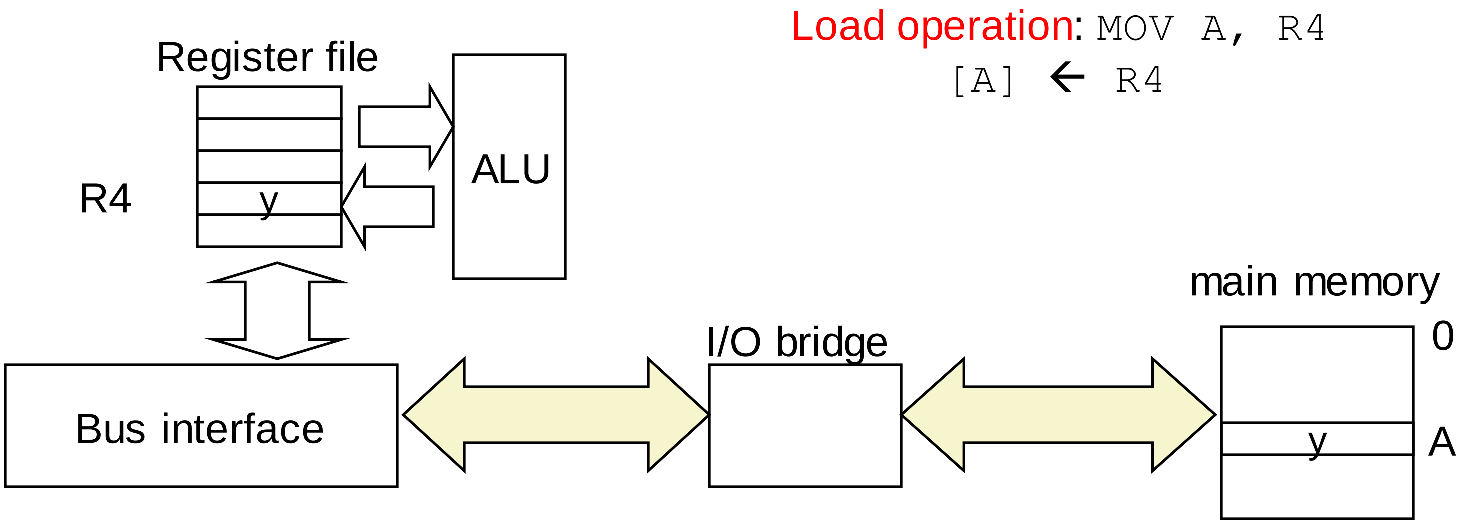


Load operation: `MOV A, R4`

`[A] ← R4`

Memory Write Operation (3)

Main memory reads data word y from the bus and stores it at address A.



Magnetic Disk Drive

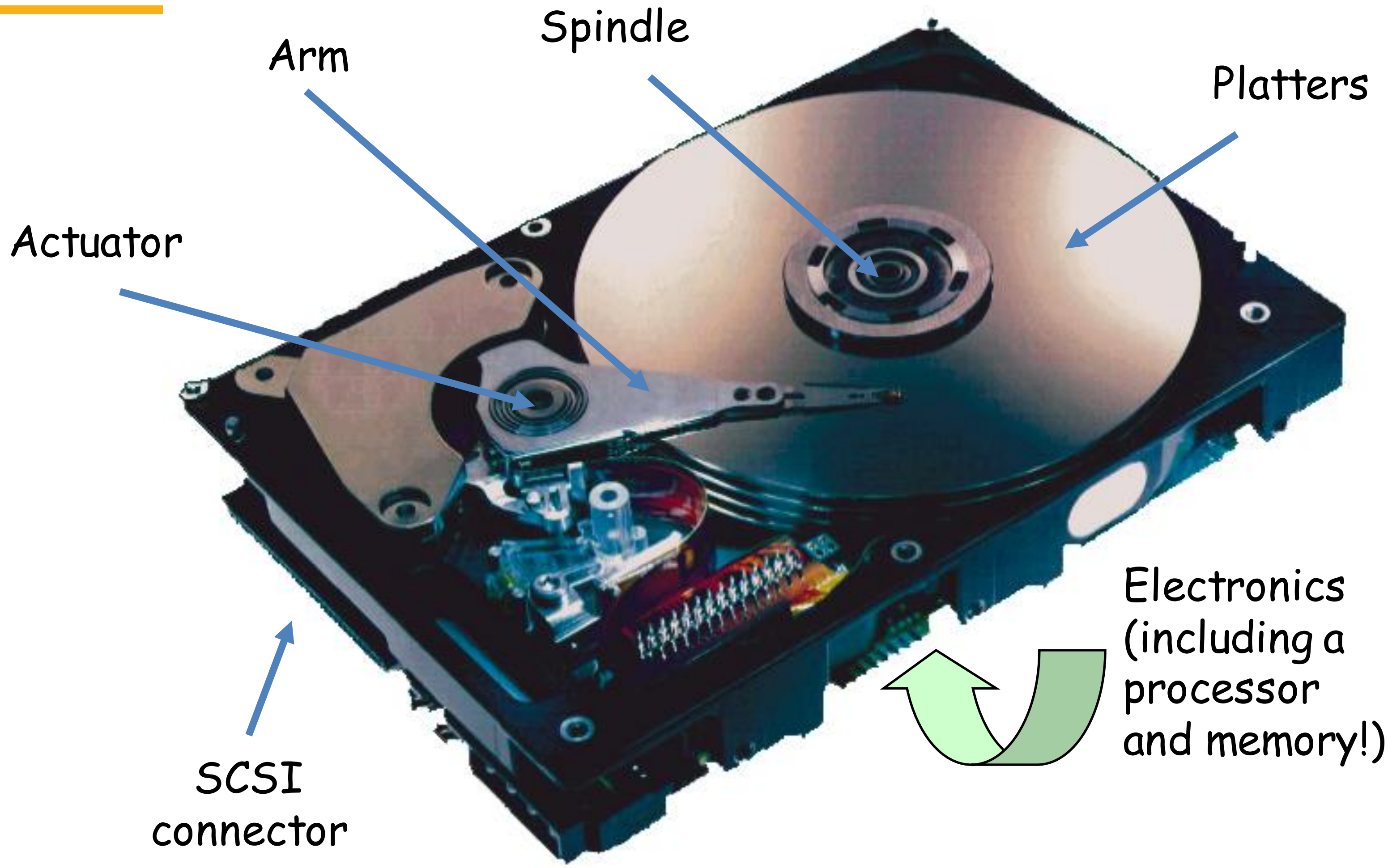
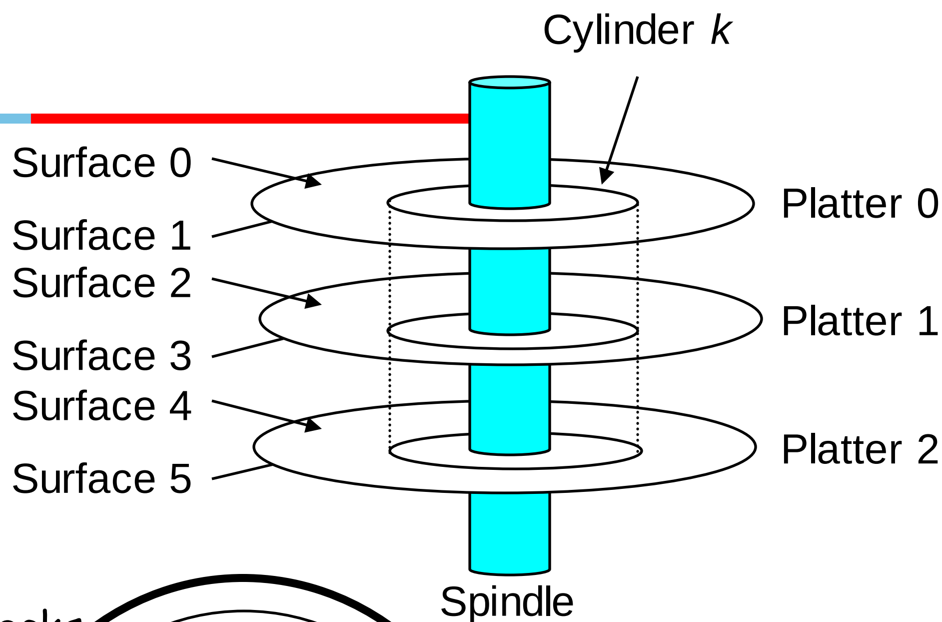
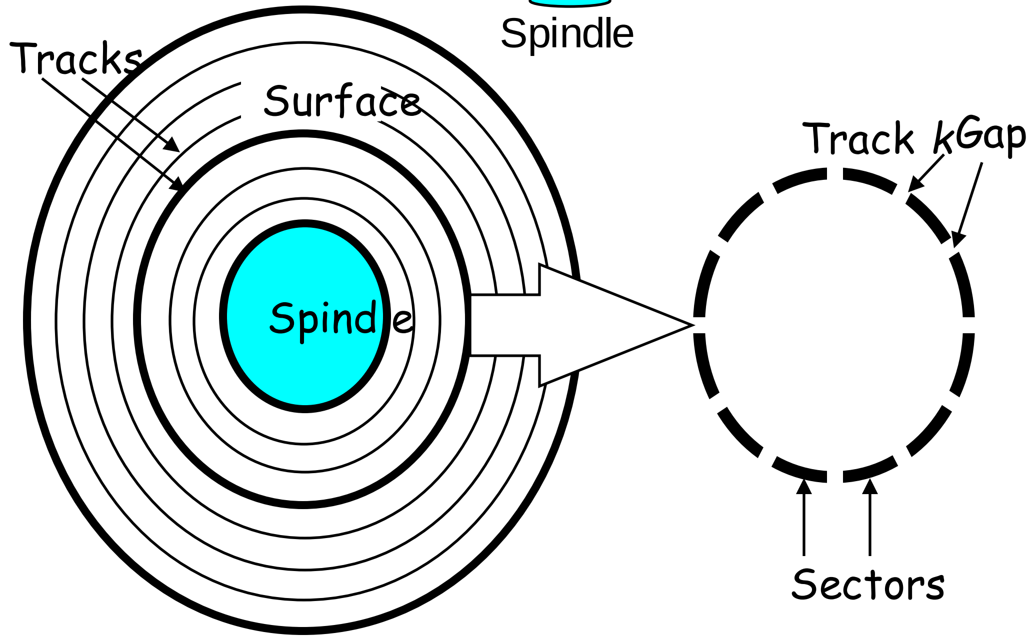


Image courtesy of Seagate Technology

Disk Geometry

- Disks consist of platters, each with two surfaces.
- Each surface consists of concentric rings called tracks
- Aligned tracks form a cylinder
- Each track consists of sectors separated by gaps.



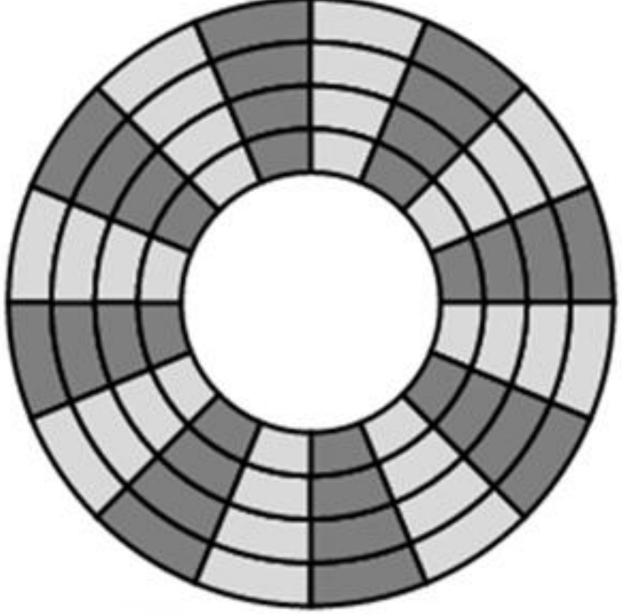


Disk Capacity

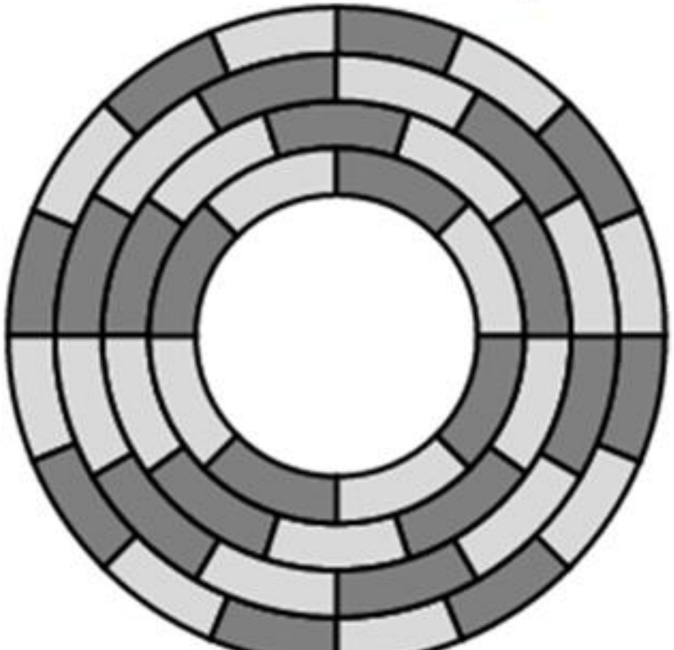
- Capacity: maximum number of bits that can be stored.
  - Vendors express capacity in units of gigabytes (GB /TB), where 1 GB = 2^{30} Bytes, 1 TB = 2^{40} Bytes,
- Capacity is determined by these technology factors:
  - Recording density (bits/in): number of bits that can be squeezed into a 1 inch segment of a track.
  - Track density (tracks/in): number of tracks that can be squeezed into a 1 inch radial segment.
  - Areal density (bits/in2): product of recording and track density.

Recording zones

- Modern disks partition tracks into disjoint subsets called recording zones
  - Each track in a zone has the same number of sectors, determined by the circumference of innermost track.
  - Each zone has a different number of sectors/track, outer zones have more sectors/track than inner zones.
  - So we use **average** number of sectors/track when computing capacity.



Without Recording Zones



With Recording Zones

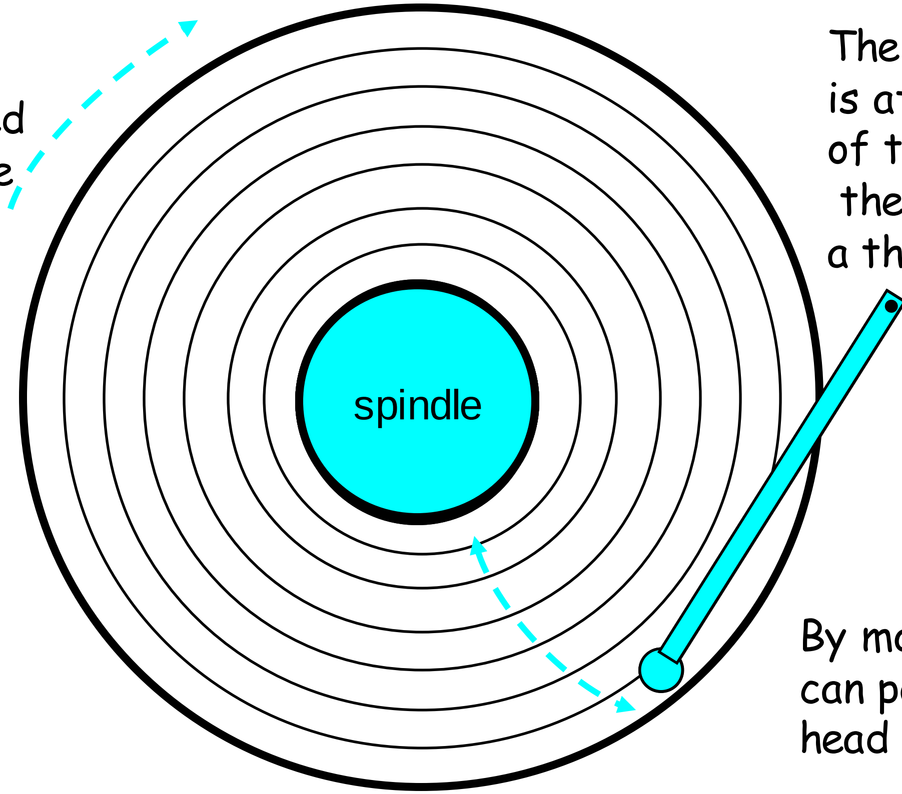
Computing Disk Capacity

- Capacity = (# bytes/sector) x (avg. # sectors/track) x
  (# tracks/surface) x (# surfaces/platter) x
  (# platters/disk)
- Example:
  - 512 bytes/sector
  - 300 sectors/track (on average)
  - 20,000 tracks/surface
  - 2 surfaces/platter
  - 5 platters/disk

- Capacity = 512 x 300 x 20000 x 2 x 5
  = 30,720,000,000
  = 28.61 GB

Disk Operation (Single-Platter View)

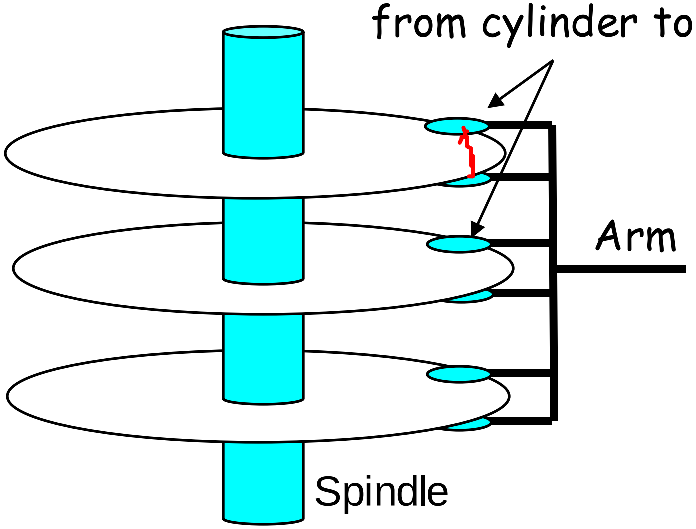
The disk surface spins at a fixed rotational rate



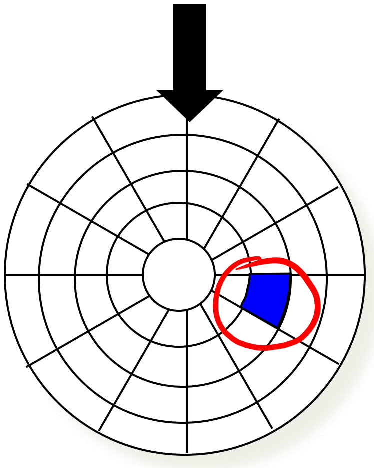
The read/write *head* is attached to the end of the *arm* and flies over the disk surface on a thin cushion of air.

By moving radially, the arm can position the read/write head over any track.

Disk Operation (Multi-Platter View)

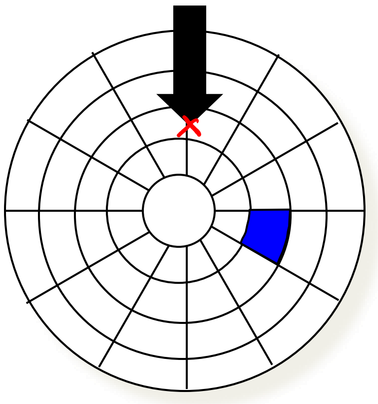


Disk Access



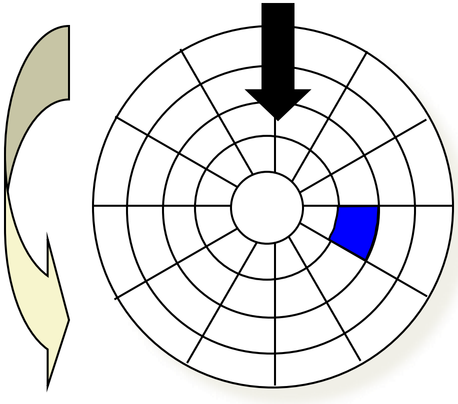
Need to access a sector colored in blue

Disk Access



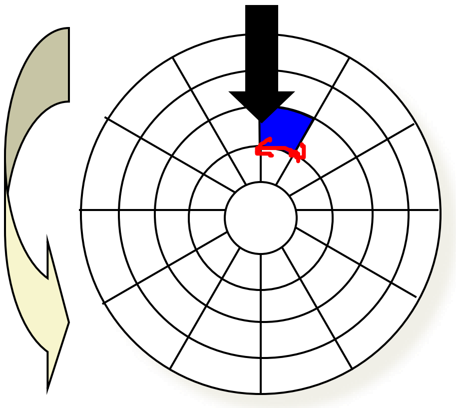
Head in position above a track

Disk Access



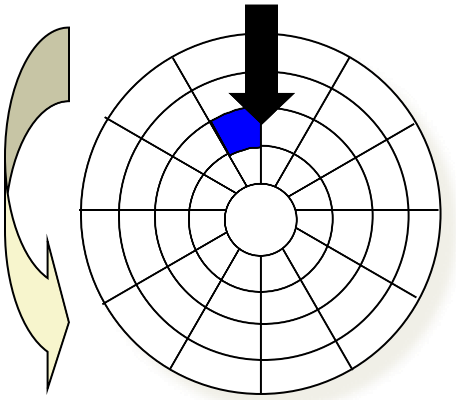
Rotate the platter in counter-clockwise direction

Disk Access – Read



About to read blue sector

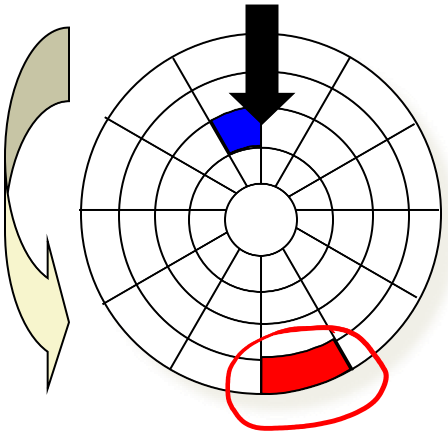
Disk Access – Read



After BLUE read

After reading blue sector

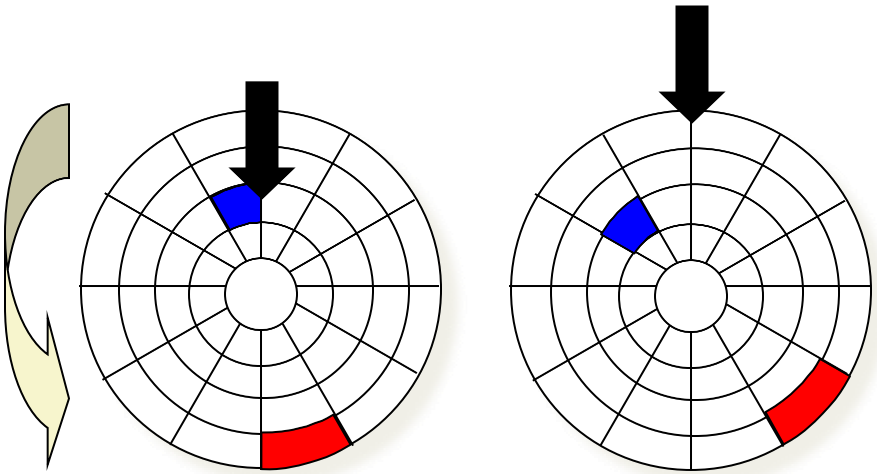
Disk Access – Read



After BLUE read

Red request scheduled next

Disk Access – Seek

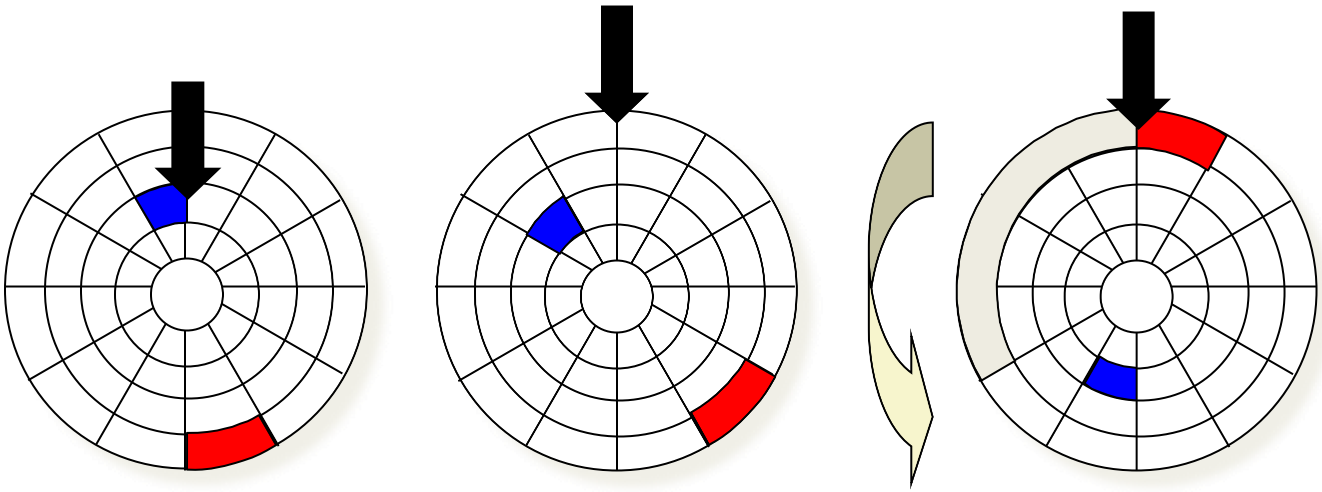


After BLUE read

Seek for RED

Seek to red's track

Disk Access – Rotational Latency



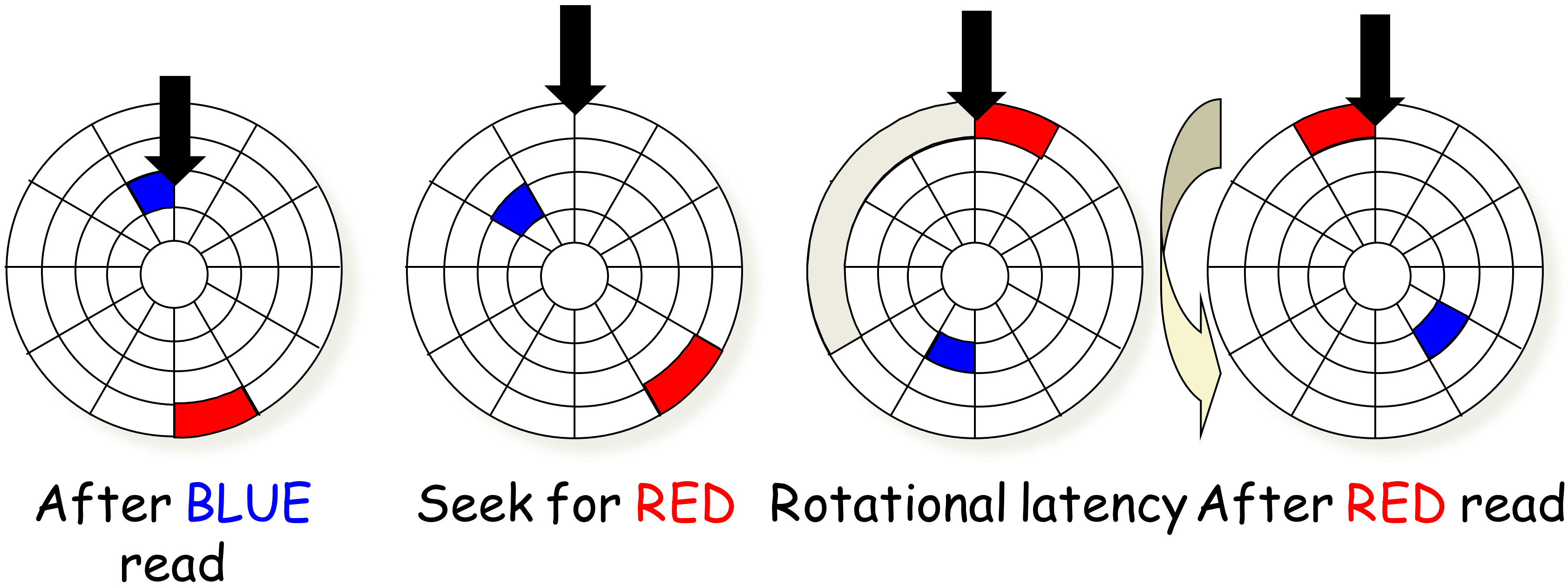
After BLUE read

Seek for RED

Rotational latency

Wait for red sector to rotate around

Disk Access – Read



Complete read of red

Disk Access – Access Time Components