Lec 5

Modern Computer Architecture

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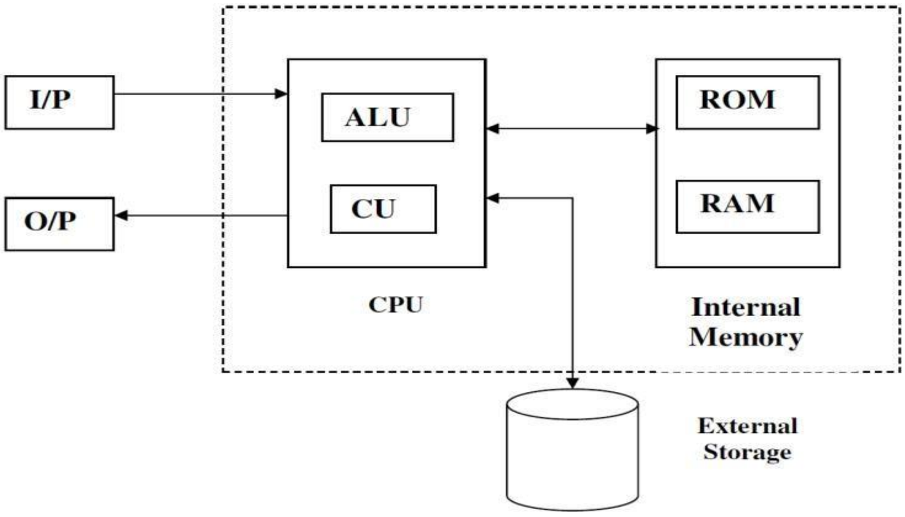
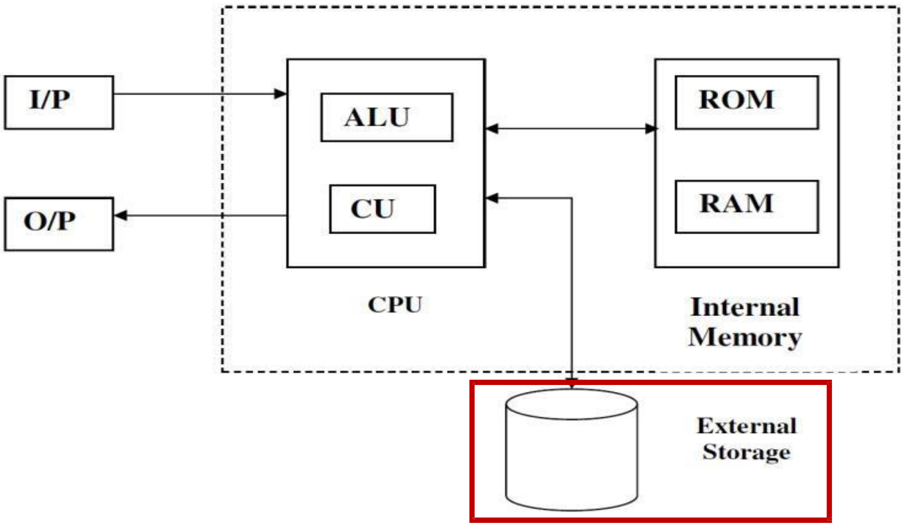


External Storage

Storage



External Storage

- Also known as Auxiliary Memory.
- It’s a secondary memory (***nonvolatile storage***).
- It stores programs and data permanently even if the power is off.
- It has many forms such as Compact Disks (CDs), Digital Versatile Disks (DVDs), and Flash Memories.

- **Advantages when compared with internal memory**
  - Non-volatile.
  - Larger storage capacity.
  - Cheaper.
  - Removable.

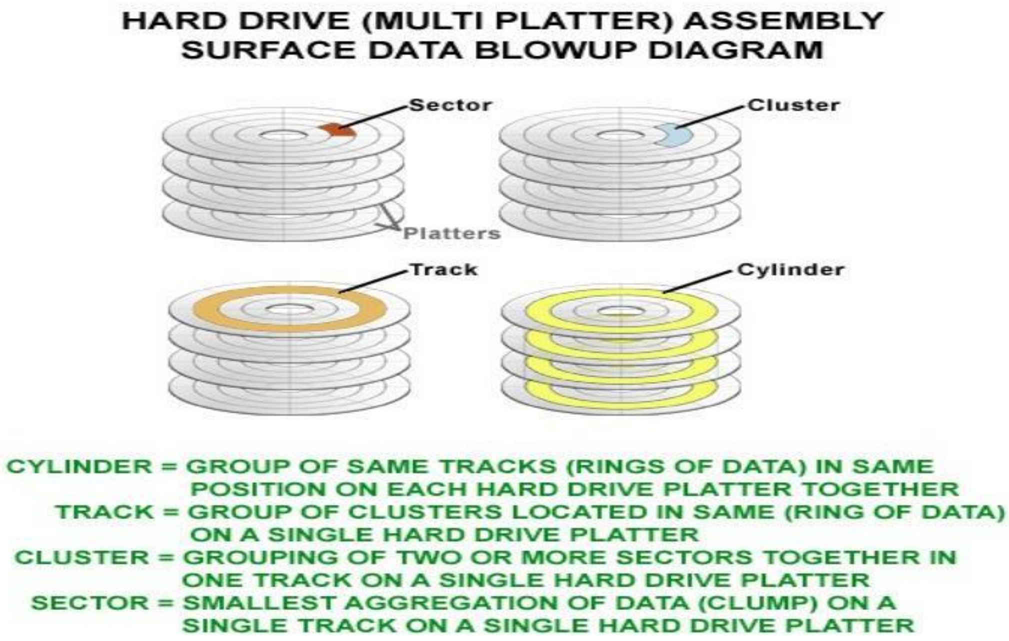
Disadvantages when compared with internal memory
  - Most of them require mechanical motion.
  - Thus, slower in data storing and retrieving.

- External storage system can be categorized according to the **storing technology**
  - **Magnetic** (example: Hard disk)
  - **Optical** (example: CD, DVD)
  - **Solid-state (special type of EPROM)** (example: Flash memory)

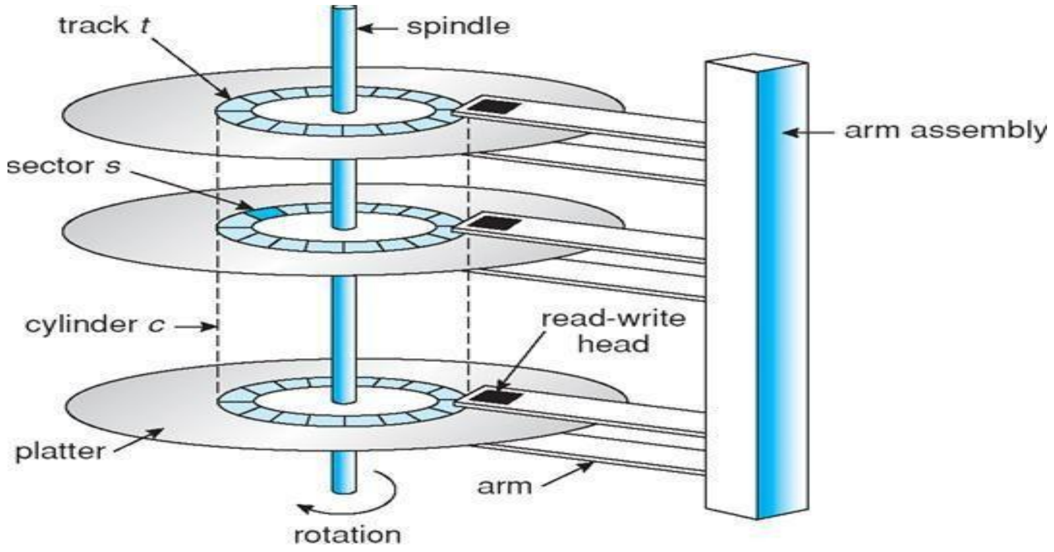
Magnetic Storage Systems

- It is based on holding data on a **thin spinning disk made of alumnium or glass and coated with magnetic material.**
- During **formatting process**, both magnetic surfaces of the thin disk is divided into concentric circles called **“tracks”** and each track is divided into arcs called **“sectors”.**
- The number of tracks per surface and number of sectors per track depends on the disk storage capacity.
- To store data, Read/Write heads are **placed above/below the disk**.
- The disk drive can **reposition the read/write head arm by mechanical motion** at any sector in any track.

Magnetic Storage Systems



Magnetic Storage Systems...



- To facilitate fast rotation speeds, the **read/write heads** in these systems do not touch the disk but instead
"float" just off the surface.
- For efficiency, hard drive store data at the same locations on all platters (cylinder) before moving to the read/write head to the next location insteadof storing data platter by platter.

Solved Exercise 1

Given a hard disk containing 4 disks, one on the top of the other. Each disk has two storing sides, with 64 track per side. Each track contains 16 sectors, and the storage capacity of each sector is 512 Bytes.

- What is the total storage capacity of the hard disk?

hard disk capacity= 4*2*64*16*512 = 4194304 Byte = 4 M

Magnetic Disk Performance Evaluation

Several measurements are used **to evaluate a disk system's performance:**

1. **Seek Time:** The time required to move the read/write heads from one track to another.
2. **Rotation Delay (Latency Time):** Half the time required for the disk to make a complete rotation, which is the average amount of time required for the desired data to rotate around to the read/write head once the head has been positioned over the desired track)
3. **Access Time = Seek Time + Rotation Delay.**
4. **Transfer Rate:** The rate at which data can be transferred to or from the disk.

Solved Exercise 2

- What is the average access time for a hard disk spinning at 50 rotation per second with a seek time of 5 millisecond?

- seek time=5 millisecond (ms)

- hard disk makes 50 rotation per second --> 1 complete rotation takes 1/50 second

- latency time= half the time for a complete rotation =
- latency time= (1/2) * (1/50) = 1/100 sec = $0.01*10^3$ ms =10 ms

- Acess time=seek time + latency time
- Acess time= 5 +10= 15ms

Solved Exercise 3

A hard disk with 15 sector per track with 512 Byte per sector spins at the rate 500 revolution per minute (rpm).
What is the number of bytes passed by the read/write head per second?

- # of rotation per minute= 500 rpm

- # rotation per second= 500/60 = 8.33rps

- track capacity (# bytes per track)=15*512= 7680 Byte

- number of bytes passed by read/write head per secod =7680*8.33= 64000 Byte per second

Optical Storage Systems

- There are three optical storage media: **Compact Disk (CD), Digital Versatile Disk (DVD) and Blue-Ray Disk (BD).**
- Their surface is made of plastic, coated with crystalized substance, then coated with an aluminum layer.
- The read/write operation is made through low-power laser light
    - **CD** uses **infrared-laser light** for storing data.
    - **DVD** uses **red-laser light** for storing data.
    - **BD** uses **blue-laser light** for storing data.
- Data is stored via **making microscopic darkspots** on its reflexive surface
- The **writing technology** of CD, DVD and BD can be **Recordable (R)** where the stored data can't be changed once it has been recorded or **Rewritable (RW)** where the stored data can be modified.

Optical Storage Systems

External Storage Evaluation

Criteria for Evaluating Different Storage Devices:

1. **Device Versatility:** the ability to access data on more than one type of media.

   For example, DVD drive can access CD and DVD while CD drive can access only CD.

2. **Technology Durability:** the ability to resist damage due to environmental factors as dust, smoke, heat, humidity, mishandling, …etc.

   For example, optical and solid-state storage devices are more durable than magnetic storage devices.

3. **Storage Capacity:** the maximum amount of data can be stored on the storage medium.

   It is usually **measured in MB,GB or TB.**

Criteria for Evaluating Different Storage Devices:

4. **Storing Device Speed:** it measured through

   A. **Access Time:** the time needed by the computer to locate the required data on the storage medium and read it. It is **measured in millisecond, microsecond or nanosecond.** (*1 second = 10^3millisecond = 10^6 microsecond = 10^9 nanosecond*).

   B. **Data Transfer Rate:** the amount of data a storage device can move per second from the storage medium to the computer. It is usually **measured in Mbps**.

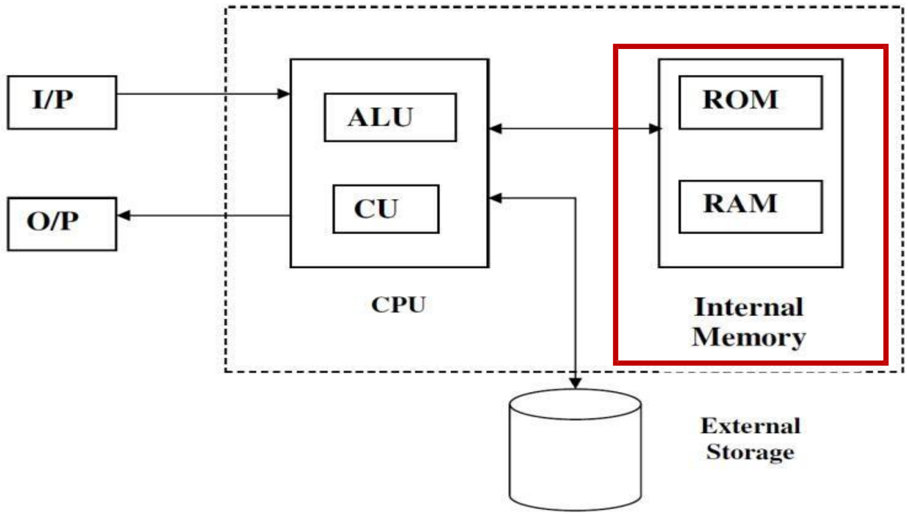
External Storage...

Classification of external storage systems based on storing technology:

Technology	Advantages	Disadvantages	Examples
Magnetic	• Flexiability for editing data • High capacity with quite low cost.	Data can be altered by dust, smoke, heat humidity, mechanical problems,…	Hard Disk
Optical	Less affected by environmental damage as dust, fingerprints, heat, humidity, magnets,.. (as its surface is made of plastic)	Less capacity than magnetic	CD, DVD, BD
Solid-State	• Higher durability than both of magnetic and optical storage • Faster access of data than magnetic and optical	Less capacity than magnetic	USB Flash

Internal Memory

Modern Computer Architecture: Internal Memory



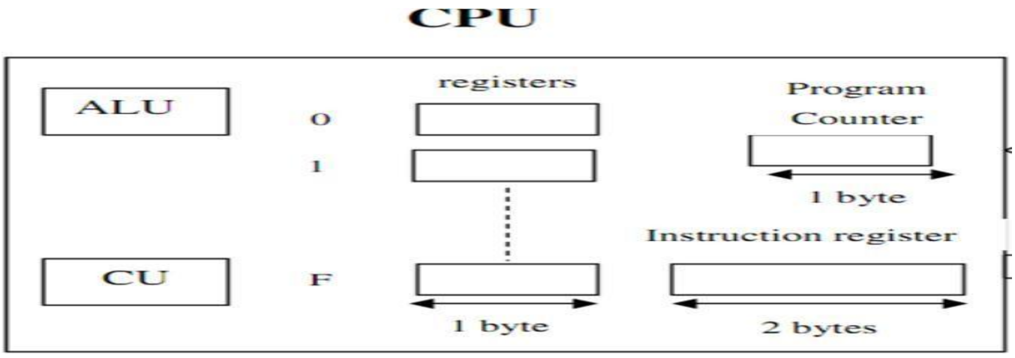
- It is composed of chips of integrated circuits which are capable of quickly storing and retrieving data.
- There are 7-types of internal memory inside a digital computer:

CPU Internal Registers.	(volatile memory)
CACHE Memory.	(volatile memory)
Random Access Memory (RAM).	(volatile memory)
Video Random Access Memory (VRAM).	
Read Only Memory (ROM).	(Non-volatile memory)
Complementary Metal Semiconductor Memory (CMOS).	(non volatile)
Virtual Memory.	(volatile memory)

CPU Internal Registers

There are **two types of registers** (volatile memory) inside the CPU:

1. **General-purpose registers:** which serves as temporary holding place of the processed data by the ALU.
2. **Special-purpose registers:** which are responsible for proper execution of the programs, e.g. “Program Counter Register (PCR)” and “Instruction Register (IR)”.



CACHE Memory

- **Very high-speed** memory acts as **temporary area (volatile memory)** between the CPU and RAM.
- This memory is typically **integrated directly with the CPU chip or placed on a separate chip** that has a separate bus interconnect with the CPU.
- The basic purpose of cache memory is **to store program instructions and data that are frequently or routinely re-referenced by the program during operation**. So fast access to these instructions and data increases the overall speed of the program execution.
- There are **three levels of CACHE memory** inside a digital computer: **L1, L2 and L3.**

- **L1 cache** is extremely **fast but relatively small, and is usually embedded in** the processor chip (CPU).
- **L2 cache** is often **larger than L1**; it may be located on the CPU or on a separate chip with a high-speed alternative system bus interconnecting the cache to the CPU, so as not to be slowed by traffic on the main system bus.
- **L3 cache** is typically specialized memory that **works to improve the performance of L1 and L2**. It can be significantly **slower than L1 or L2**, **but is usually larger than them and double the speed of RAM**.

Read Only Memory (ROM)

- Contains small set of **never-changed instructions called “Basic Input/Output System” (BIOS)** which tell the computer how to access the hard disk, find the operating system and load it into RAM.

- **Types of ROM:**
  1. **Programmable ROM (PROM):** written and programmed once.
  2. **Erasable Programmable-ROM (EPROM):** erased and reprogrammed many times.

  Flash Memory: a special type of EPROM used as storage device in digital cameras, cell phones and home video game consoles.

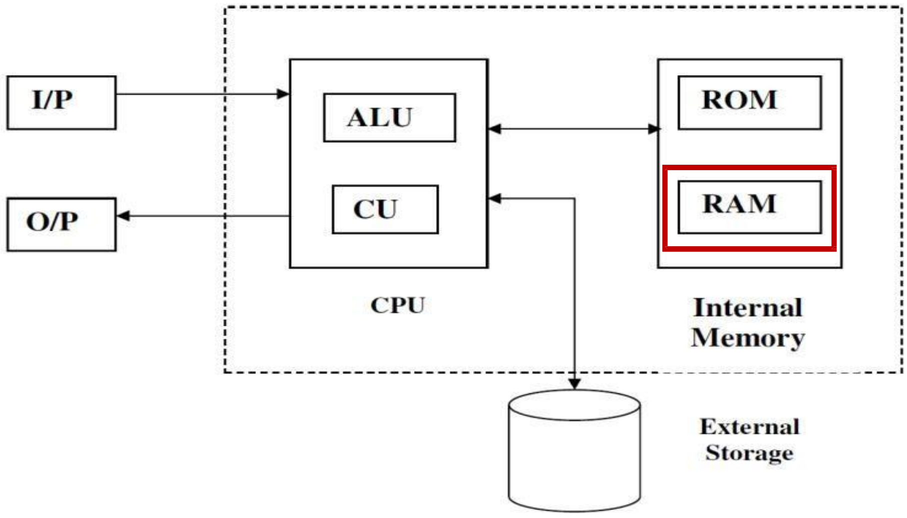
Complementary Metal Semiconductor Memory (CMOS)

- CMOS memory chip stores the computer configuration settings such as date/time, hard disk capacity, RAM capacity, …etc.
- Any change in computer configuration settings updates the CMOS data.
- CMOS is powered by a small battery that’s integrated into the motherboard
- The battery helps CMOS to keep its data when the computer power is off.
- The battery is automatically recharged while the computer power is on.
- CMOS is more permanent than RAM and less permanent than ROM.

Virtual Memory

- A way of expanding the memory of a computer using a specified space on the hard disk.
- If the running program is quite large to fit into RAM, it’s divided into fixed-size parts called “**pages**”.
- It’s the job of the operating system to swap pages between RAM and virtual memory on the hard disk and vice-versa.
- Since the read/write speed of hard disk is slower than it of RAM, it’s preferable to increase the RAM size than to increase the virtual memory size in the computer.

RAM



Random Access Memory (RAM):

- It's the main memory of the computer.
- It stores the programs and their data which are needed to be executed by the CPU.
- The CPU can **read from and write to** RAM .
- When the power is off, all the stored data in RAM are lost (***volatile memory***).
- When you buy a computer, you pay for RAM not ROM.

RAM Organization

address of a memory cell
- each cell has a unique memory address
- address is used to access a memory cell (read/write)
- address contains at least 8 bits (0, 1) or multiple of 8 bits (address size).
- n-address line(address size): is the number of bits representing the address

address	cell
7F (0111 1111)	11010000
7E (0111 1110)	00011010
7D (0111 1101)	00110101
7C (0111 1100)	10101010
7B (0111 1011)	01010101
7A (0111 1010)	00101010
.	.
.	.
00 (0000 0000)	OS

memory cell (word)
- each cell stores data and programs to be executed
- it contains at least 8 bits (0, 1) or multiple of 8 bits. [word size]
- 8 bit is called byte

RAM Organization ...

address	cell
FF (1111 1111)	11010000
FE (1111 1110)	00011010
	00110101
	10101010
.	01010101
.	00101010
.	.
.	.
00 (0000 0000)	OS

if n-address line=8
if address is 0000 0000
the last address is 1111 1111 (FF)

size of each word is 8 bits =1 byte

n-address line= # bits in the address (address size)
1st address= 0000 ... 0000
last address=$2^{n\text{-addressline}} - 1$
=1111 1111

$2^{n\text{-address line}}$= # of words(n)

Memory Size= N*M
N: # of words
M: size of each word (in byte)

- The RAM of digital computers consists of a large number of "**memory cells**" where each **memory cell is called a "word"**.
- With this memory organization, **each memory cell is addressed, accessible and modified individually**.
- A **"word"** or a cell in memory is an entity of bits (group of 1's and 0's) that can be moved in and out of the memory as a unit.
- The **size** of a memory **word** is **multiples of 8-bits** in length: **8-bits (i.e.,1 byte), 16-bits (i.e., 2 bytes) , or 32-bits (i.e., 4 bytes)**, and so on .

RAM Capacity

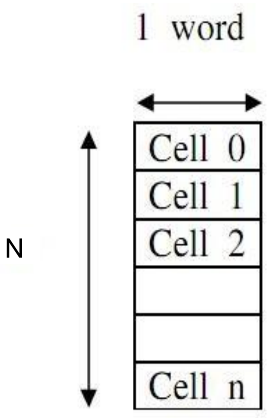
The capacity of the RAM is simply the total number of bytes that it can store.

The capacity of memory=number of words (N) * word size(M) in byte

The capacity of memory = N words

= N * M bytes

= N * M * 8 bits



Memory Size= N * M
N: # of words
M: size of each word (in byte)
N (# word)= $2^{n\text{-address line}}$
n-address line= #bits in the address
1st address= 0000 ... 0000
last address=$2^{n\text{-addressline}} - 1$
=1111 1111

The units that are usually used for measuring storage capacities:

UNIT	ABBREVIATION	MEANING
bit	b	1 binary digit
Byte	B	8 bits
Kilobit	Kb	2^{10} b = 1024 bits
Kilobyte	KB	2^{10} B = 1024 bytes
Megabit	Mb	2^{20} b = 1024 Kb
Megabyte	MB	2^{20} B= 1024 KB
Gigabit	Gb	2^{30} b = 1024 Mb
Gigabyte	GB	2^{30} B = 1024 MB
Terabyte	TB	2^{40} B = 1024 GB

RAM Capacity: Example

Example(1): The following memory capacities are measured in words, obtain the equivalent capacities in terms of bytes and bits.

i- 1K words with 16 bits each

ii- 16 M words with 32 bits each

iii- 2048 words with 8 bits each

Solution:

i- Memory capacity $= 1\text{ K} \times 2\text{ B} = 2\text{ K B} = 2 \times 1024\text{ B} = 2048\text{ B}$

$= 1\text{ K} \times 16\text{ b} = 16\text{ K b} = 16 \times 1024\text{ b} = 16384\text{ b}$

ii- Memory capacity $= 16\text{ M} \times 4\text{ B} = 64\text{ MB} = 64 \times 1024 \times 1024\text{ B}$

$= 67108864\text{ B} = 67108864 \times 8\text{ b} = 536870912\text{ b}$

iii- Memory capacity $= 2 \times 1024 \times 1\text{ B} = 2048\text{ B} = 2\text{KB}$

$= 2\text{ K} \times 8\text{ b} = 16\text{ K b} = 16384\text{ b}$

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ii- Memory capacity = $16\ M \times 4\ B = 64\ MB = 64 \times 1024 \times 1024\ B$

$= 67108864\ B = 67108864 \times 8\ b = 536870912\ \ b$

iii- Memory capacity = $2 \times 1024 \times 1\ B = 2048\ B = 2KB$

$= 2\ K \times 8\ b = 16\ K\ b = 16384\ b$

RAM Addressing...

Example 2: What is the total memory capacity that can be addressed using a CPU with 16-address line?

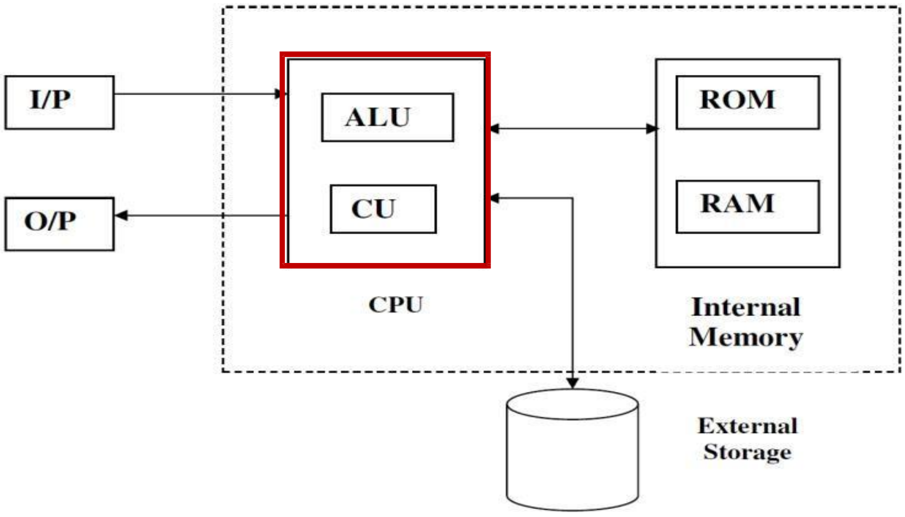
Solution: The total memory capacity = $\mathbf{2^{16} = 2^{6} \times 2^{10}}$ **= 64 Kilo word (KW).** If each word = **1 byte**, then the total memory capacity = **64 KB**. The address of the first memory cell = **0000 0000 0000 0000**.The address of the last memory cell = **1111 1111 1111 1111**.

In other words , using hexadecimal notation, the address range is: **0000 to FFFF**.

Example 3: what is the total number of address lines needed by a CPU to address memory of capacity of 64 MB?

Solution: The total memory capacity = $\mathbf{2^{6} \times 2^{20} = 2^{26}}$ **B**. If each word (cell) = **1 byte**, then the total memory capacity = $\mathbf{2^{26}}$**word (cell)** , thus the number of address lines is **26**.

Microprocessor



The microprocessor (or processor) is an integrated circuit that contains the computer's central processing unit (CPU) CPU: executes programs stored in the main memory

Central Processing Unit (CPU)

Central Processing Unit (CPU):

the main unit of the computer
responsible for executing programs stored in the internal
memory. It consists of two parts:

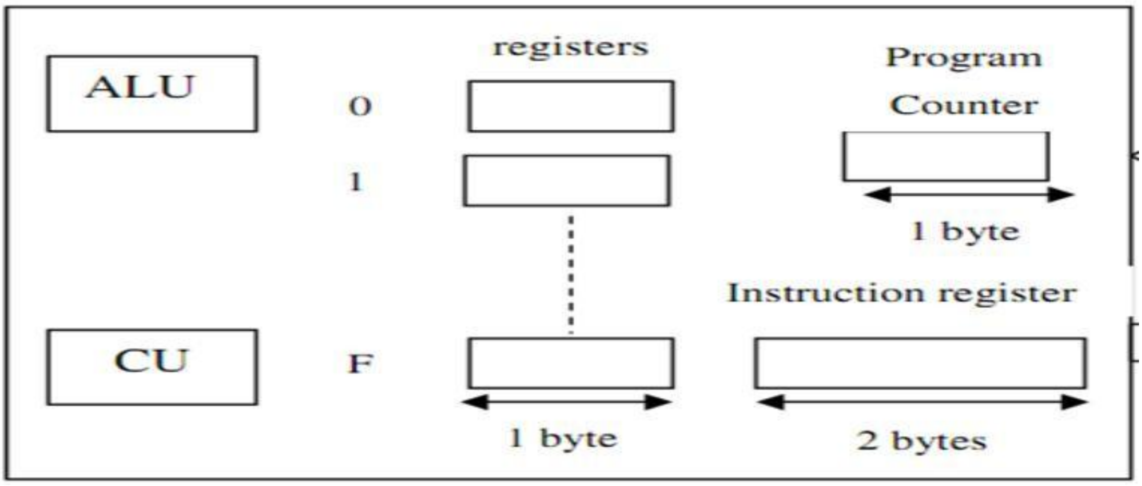
1) Arithmetic and Logic Unit (ALU) .
2) Control Unit (CU) .
3) **Arithmetic and Logic Unit (ALU):** performs:
   - Arithmetic operations: Addition, Subtraction, Multiplication, Division, Modulus, Power,… etc.
   - Logical: AND, OR, XOR, SHIFT, ROTATE,…etc.
4) **Control Unit (CU):**

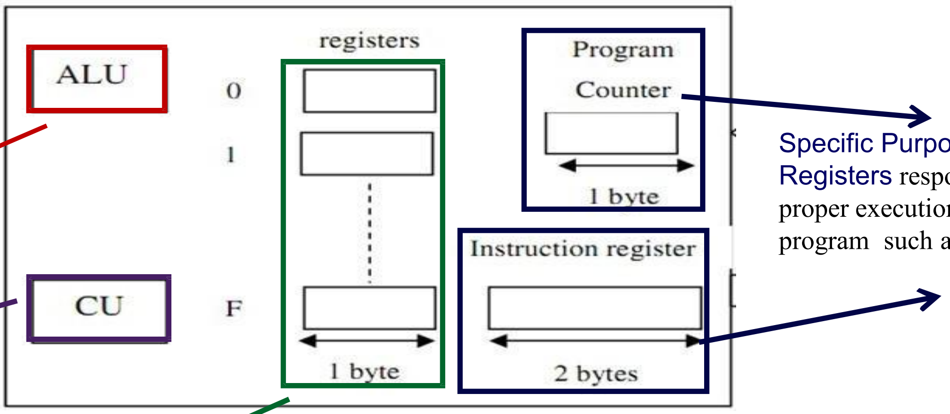
   responsible for controling all the CPU operations, such as:
   - Decoding the instructions of programs stored in the internal memory.
   - Controlling the flow of information through the ALU, I/O, and internal memory.

Microprocessor (processor)

The microprocessor (or processor) is an integrated circuit that contains the computer's central processing unit (CPU) CPU: executes programs stored in the main memory

CPU





performing arithmetic and logical operations

responsible for coordinating the machine's activities

Specific Purpose Registers responsible for proper execution of the program such as: PCR, IR

General Purpose Registers
temporary storage cells
hold data to being processed
their number and size: determine the speed and power of the computer

Micoprocessor

The microprocessor (or processor) is an integrated circuit that contains the computer's central processing unit (CPU) which executes programs that are **stored** in the internal main memory (RAM) of the computer.

A microprocessor has **two** main **components:**

1. **Arithmetic & Logic Unit (ALU):** is responsible for performing arithmetic and logical operations
2. **Control Unit (CU) :** is responsible for coordinating the computer's activities.

The ALU uses internal temporary storage cells, called **registers**, to hold data that is being processed.

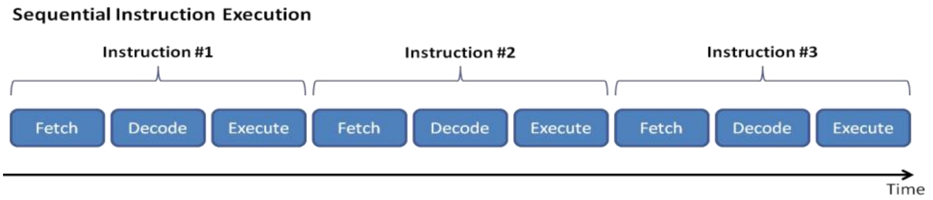
The **size** and **number** of **registers** are critical in **determining** the **speed** and **power** of a **computer**

Microprocessor Types

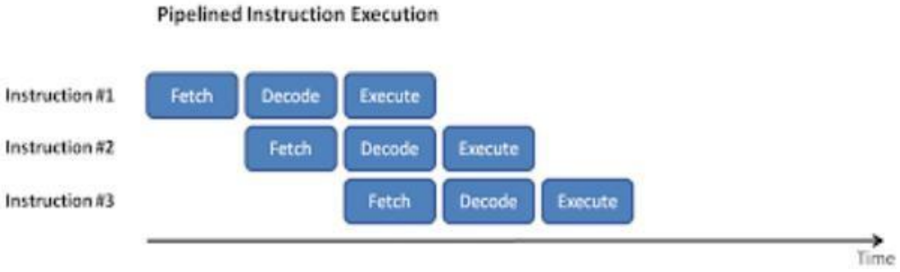
- **Serial:** The processor must complete all steps in the instruction cycle before it begins to execute the next instruction.
- **Pipelining:** The processor can begin executing an instruction before it completes the previous one.
- **Parallel:** The processor can execute multiple instructions at the same time, such as:
  Multi Core, which allows a single chip containing the circuitry of multiple processors (2, 4, 8, or 16) with a shared cache memory.

Microprocessor Types...

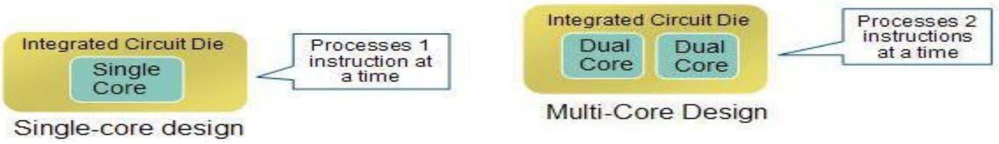
Serial



Pipeline



Parallel



Microprocessors Performance

- Microprocessors' performance is affected by the following factors:

Clock speed (or clock rate):

- It is the speed at which a computer's microprocessor is able to process data.
- It is usually measured in hertz, generally in GHz, (i.e. billion cycles per second).
- For example, a CPU with a clock rate of 3 GHz can perform 3,000,000,000 billion clock cycles of (fetch-decode-execute) per second.

Word Size:

- It is the number of bits that a microprocessor can manipulate at one time.
- It is based on the size of the registers of the ALU as well as the width of the data bus. For example, 32-bit microprocessor can process 4-bytes at a time, while 8-bytes microprocessor can process 8 bytes at a time.

Processing Technology:

- Technology used for executing instructions; serial, piplined, or parallel processing

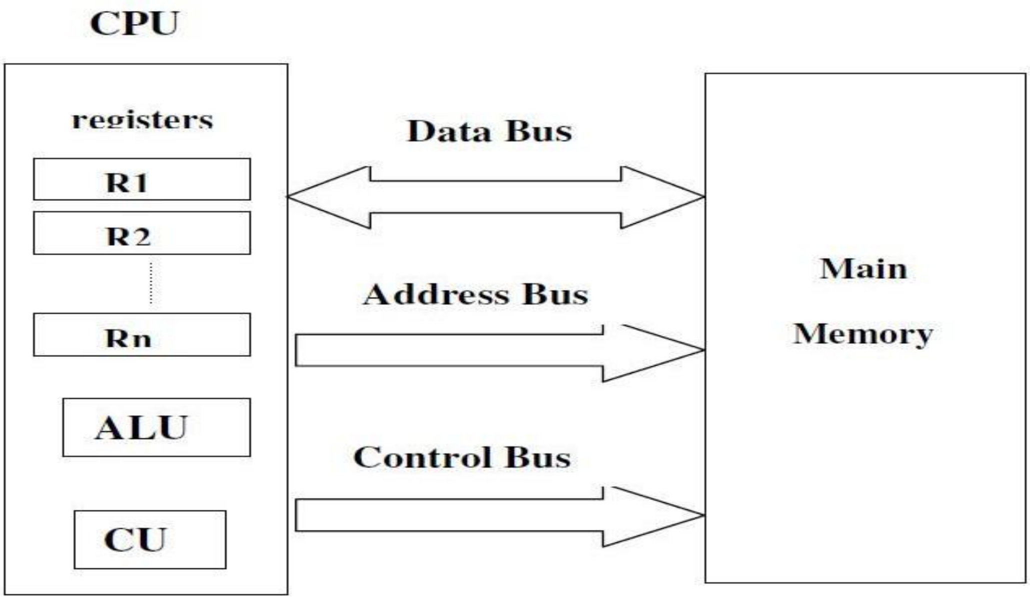
Cache size

Data Manipulation

To perform an operation on data stored in main memory:

1. CU transfers the data from memory into the general-purpose register.
2. CU informs the ALU which general-purpose register hold the data.
3. CU activates the appropriate circuitry within the ALU based the content of the instruction register.
4. CU tells the ALU which general-purpose register should receive the result.

CPU/Memory Interface



Read/Write From Memory

To write (or store) data in a memory cell:

1. CPU sends the address of the memory cell through the address bus.
2. CPU sends the data to be stored through the data bus.
3. CPU sends a write control signal through the control bus.

To read data from a memory cell:

1. CPU sends the address of the memory cell through the address bus.
2. CPU sends a read control signal through the control bus.
3. CPU receives the contents of the required memory cell through the data bus and holds it in a general-purpose register.