INTRODUCTION TO EMBEDDED SYSTEMS USING ARDUINO

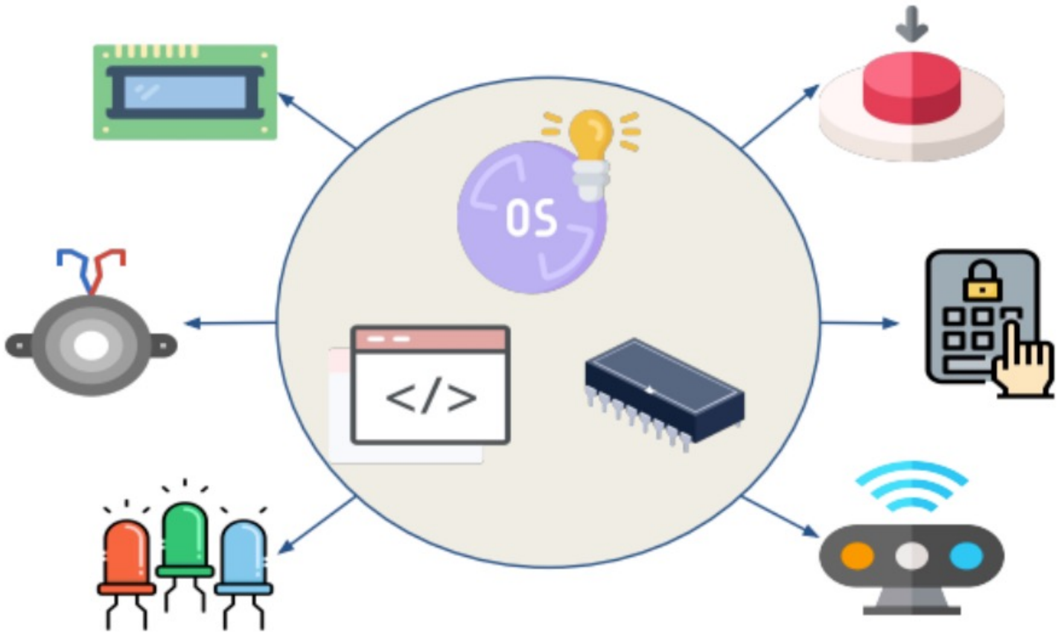
Day 1

AGENDA

1. What is Embedded Systems?
2. What is Microcontroller?
3. Microcontroller VS microprocessor
4. Instruction Set Architecture
5. Computer Architecture
6. What is Memory & Memory Types?

WHAT IS EMBEDDED SYSTEMS?

- Embedded system is an integrated system that is formed as a combination of computer hardware and software for a specific function.
- It is a hardware controlled by a software to perform a specific and periodic functionality
- may work independently or attached to a larger system to work on a few specific functions
- It may be real-time or not



EMBEDDED SYSTEM VS PC

Embedded System

- Mostly designed using a Microcontroller
- Specific Purpose
- Limited Resources
- Requires a smaller number of peripheral devices

Personal Computer

- Designed using a microprocessor
- General Purpose
- Huge Resources
- Huge number of peripheral devices

EMBEDDED SYSTEM CHARACTERISTICS

- Single-functioned: Repeated single functionality
- Tightly constrained
  - Small size
  - Low power Consumption
- Use Microprocessors or Microcontrollers.
- Limited Memory
- Connected: must be connected to input and output devices.
- Reactive and Real time: reacts to change in system environment
- Less Human intervention
- Highly Stable: Embedded systems do not change frequently
- High Efficiency

ADVANTAGE & DISADVANTAGE

- Advantages
  - Small size
  - Lower Power consumption
  - Lower cost
  - Enhanced (real-time) performance
  - Easily Customizable for a specific application
- Disadvantages
  - High development effort & cost
  - Time-consuming design process
  - Limited resources, memory, processing power

EMBEDDED SYSTEM APPLICATIONS

- **Automotive:** Cruise control, light control, ABS, EBD,ESP, ... etc.
- **Networking:** Routers.
- **Fintech:** ATM, Point Of Sale, Vending machines, ... etc.
- **Home appliances:** Home automation, Air conditioners, microwave ovens, washing machines and dishwashers, . etc.
- **Biomedical**: Wearable devices, Teleradiology, … etc.
- **Military**: Missile targeting systems, command-and-control systems, electronic warfa etc.
- **Consumer Electronics**: MP3 players, television sets, mobile phones, video game consoles, digital cameras, GPS receivers, printers, ... etc.

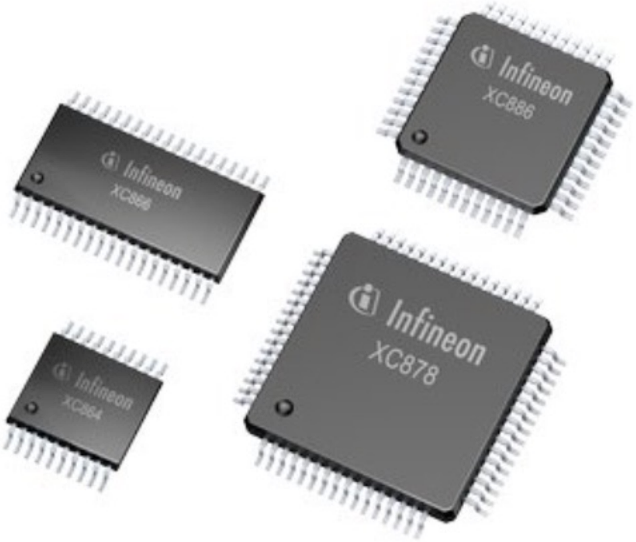
WHAT IS MICROCONTROLLER

A **microcontroller** (µC, uC or MCU) is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals.

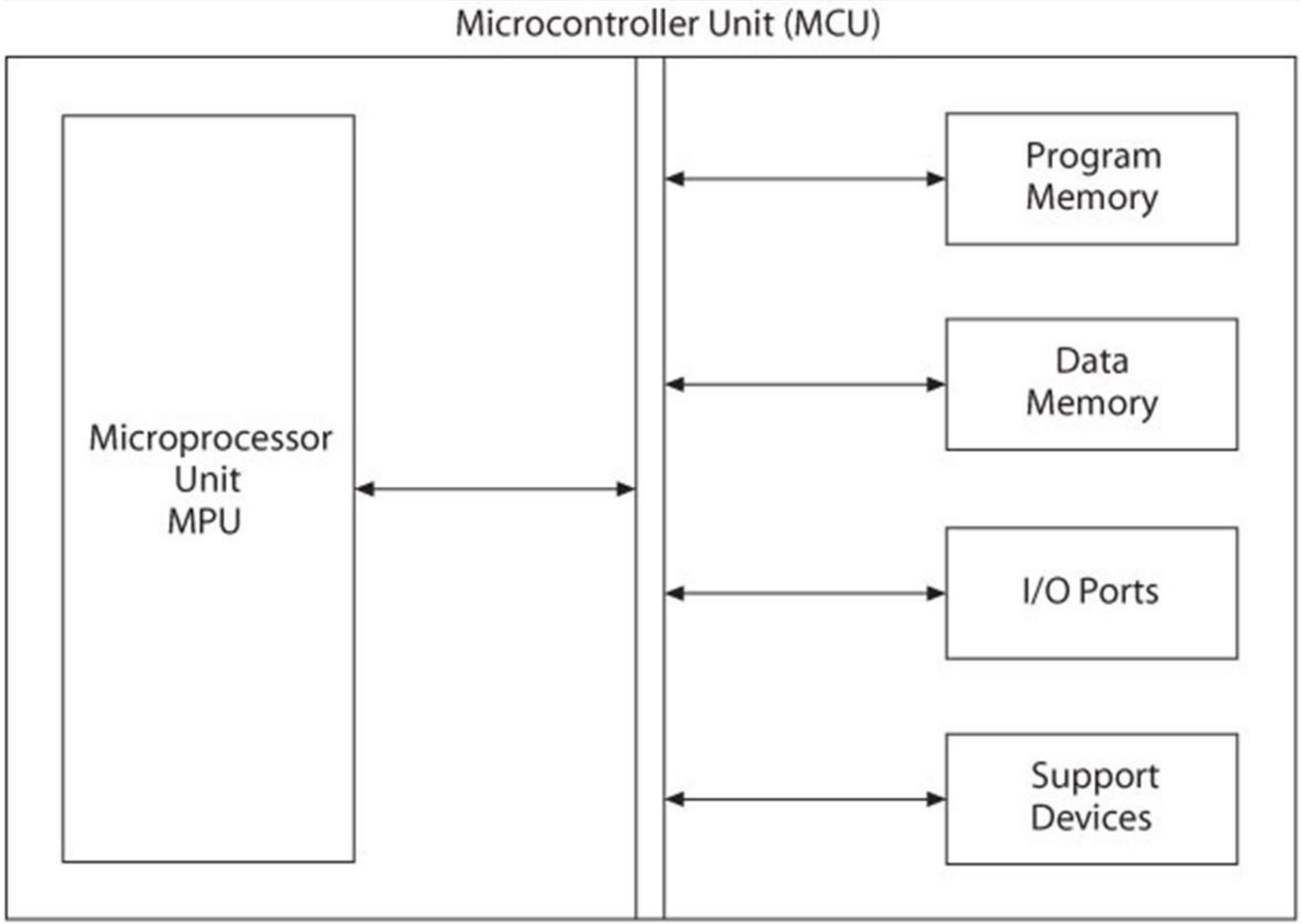
Very common component in modern electronic systems (peripherals)

Examples

- PIC
- ATMEL
- ARM



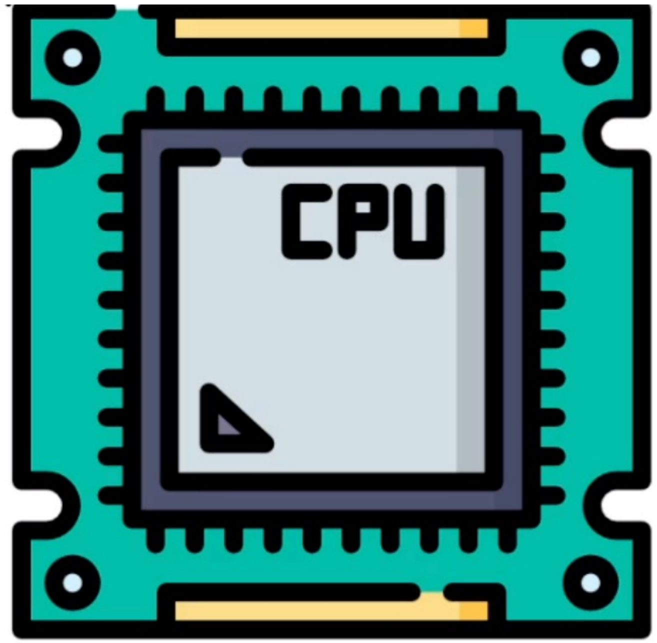
WHAT IS MICROCONTROLLER



WHAT IS A MICROPROCESSOR

A **microprocessor** is an Integrated Circuit unit in a computer system that performs logical, arithmetic and controlling operations.

- It is called also Central Processing Unit.
- The CPU is the brain of any microcontroller.
- It executes all the instructions provided by a program.



MICROPROCESSOR INTERNAL COMPONENTS

Arithmetic and logic unit (ALU):

is responsible for all arithmetic and logical operations

Registers:

Are used to facilitate CPU operations

Control Unit:

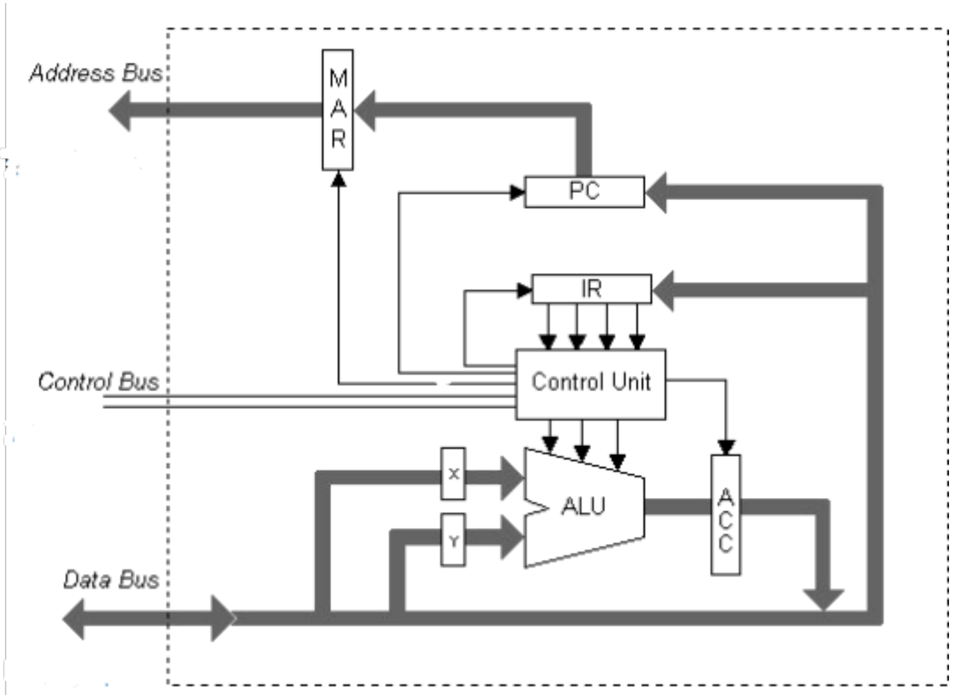
is responsible for controlling all CPU operations

Data bus:

Data bus: Data carrying wires

Address bus: address carrying wires

Control bus: read/write control signals carrying wires



CPU REGISTERS

Registers are the fastest types of memories.

It is used to facilitate CPU operations.

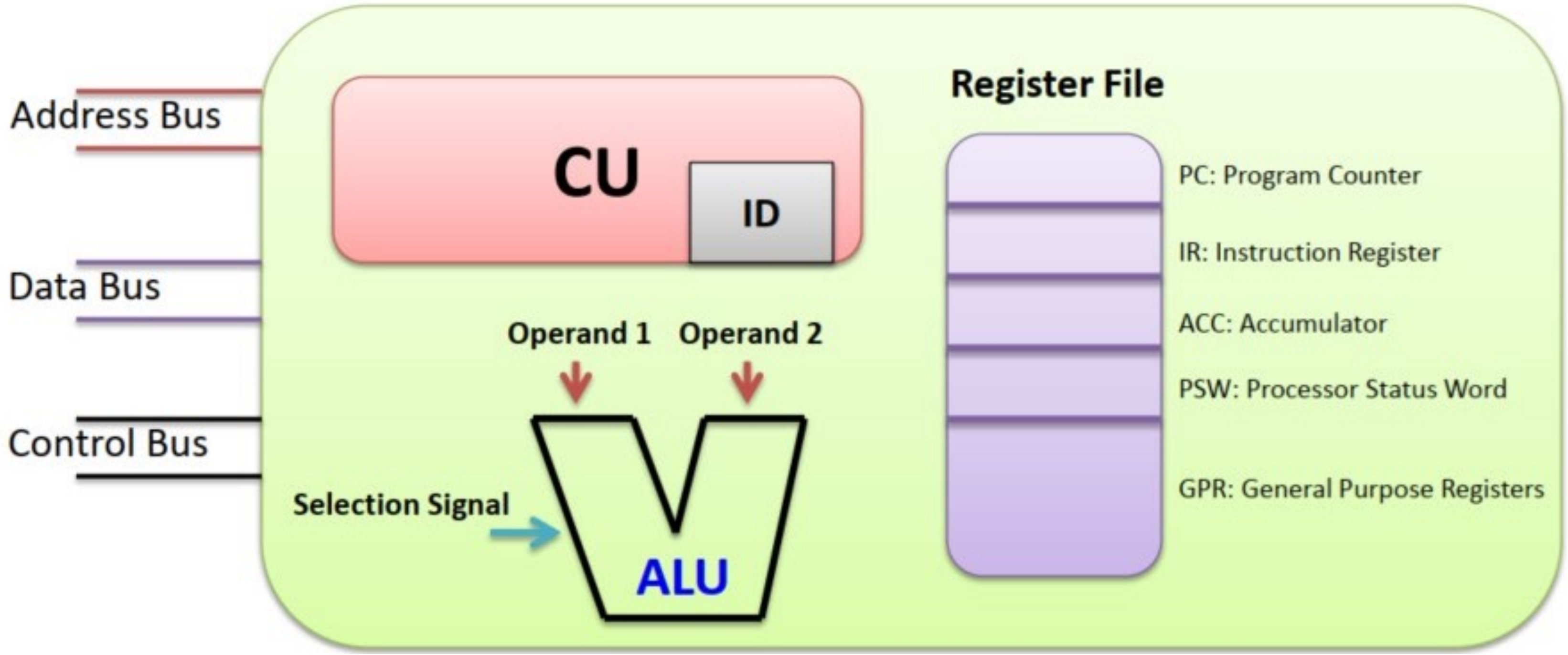
General Purpose Registers

- These are used for internal storage

Special Purpose Registers

- Status Register: It contains information about the state of the processor
- Program Counter: It contains the memory address of the next instruction to be fetched
- Accumulator: This is the most frequently used register used to store data taken from memory
- Instruction Register: It holds the instruction which is just about to be executed
- Memory Address Register and Memory Data Register: These facilitates memory R/W operations

PROCESSOR COMPONENTS



INSTRUCTION CYCLE

Fetch:

- PC points to the instruction to be executed
- Get instruction Opcode from memory and store it into IR

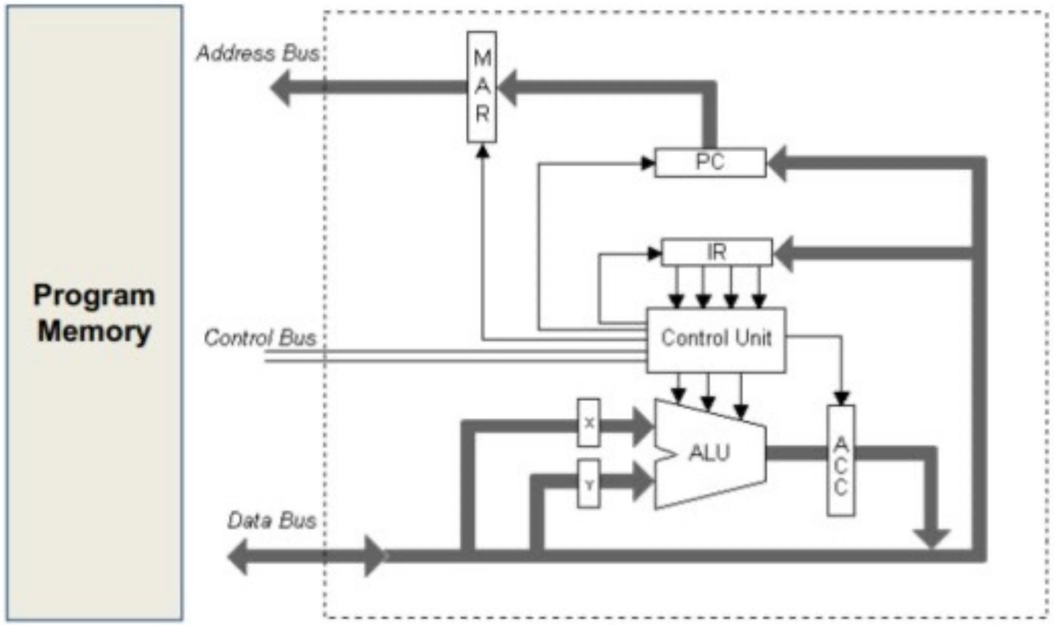
Decode:

- Know what operation will be done

Execute:

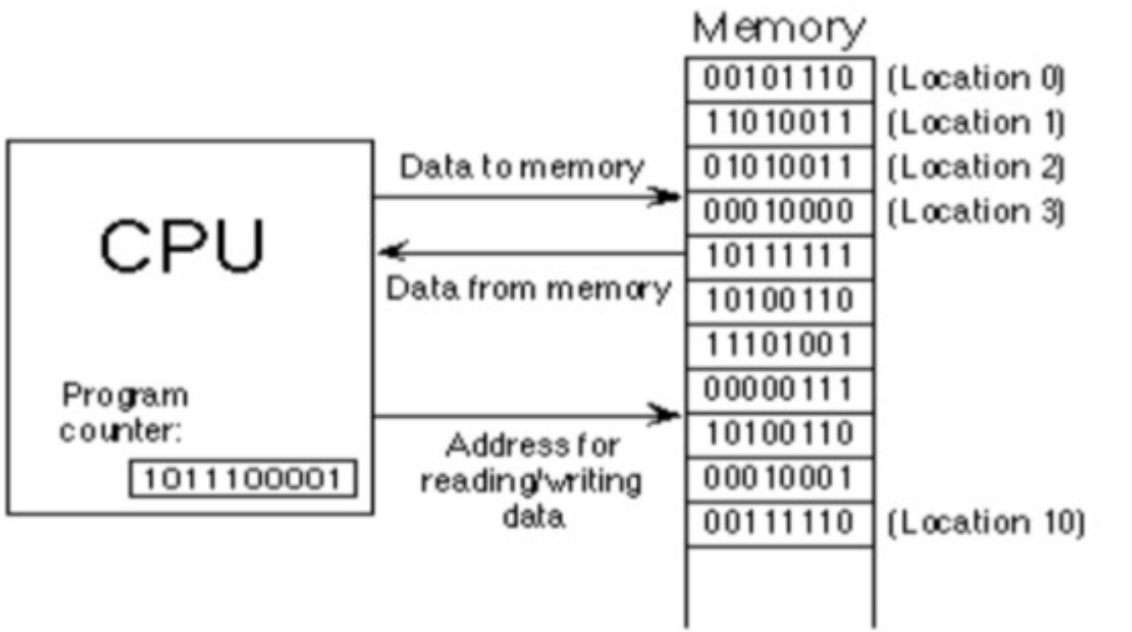
- The ALU to execute the instruction

Store



INSTRUCTION CYCLE

Fetch: At the beginning of the fetch cycle, the address of the next instruction to be executed is stored in the Program Counter(PC)



INSTRUCTION CYCLE

Decode: inside CU ”Control Unit” by ID “Instruction Decoder”.

- Every processor has its instruction set which is the group of instructions that could be executed by the processor.
- Every instruction has a unique binary representation called “Opcode”.
- The decoding step is responsible for defining the operation required by the instruction fetched from the memory
- then pass these information to the ALU.

Example

- 101 is the op code for SUB operation.
- This means that this instruction is: SUB 6 3

Instruction Format

Op Code	Operand 1	Operand 2
3 bit	3 bit	2 bit

10111011

101	**110**	**11**

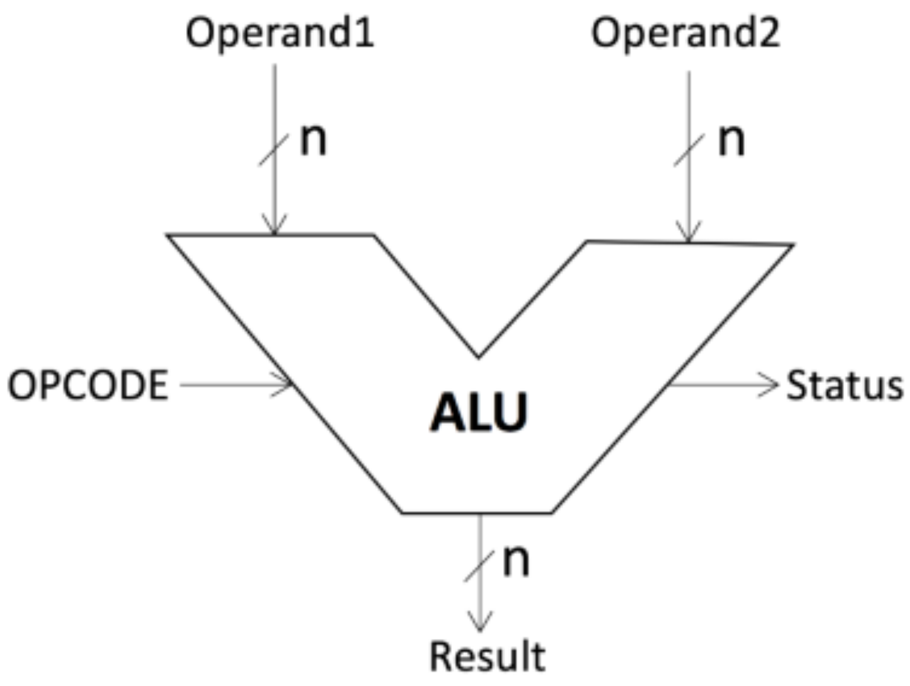
Instruction Set

Instruction	Op Code
ADD	011
SUB	101
AND	110
OR	001
XOR	111
SHIFT	100

INSTRUCTION CYCLE

Execute : By ALU “Athematic Logic Unit”.

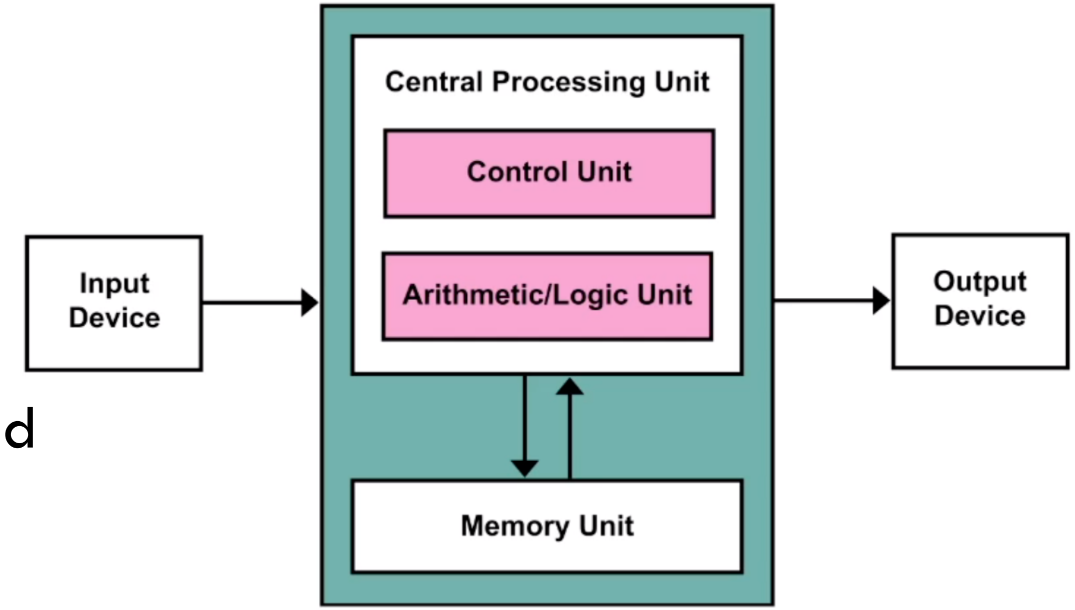
- It contains many logic gates for all the supported instructions.



WHAT IS COMPUTER ARCHITECTURE?

It is a set of rules and methods that describe the functionality, organization, and implementation of computer systems.

It is mainly concerned with CPU, memory, and I/O devices interactions.



INSTRUCTION SET ARCHITECTURE

It describes the design of a Computer in terms of the basic operations it must support.

It defines the types of instructions to be supported by the processor.

- Arithmetic/Logic, Data Transfer, and Branch and Jump Instructions.

It defines the maximum length of each type of instruction.

It defines the Instruction Format of each type of instruction.

It is classified into:

- Complex Instruction Set Computing (CISC)
- Reduced Instruction Set Computing (RISC)

REDUCED INSTRUCTION SET ARCHITECTURE (RISC)

- The main idea behind this is to make hardware simpler by using an instruction set composed of a few basic steps for loading, evaluating, and storing operations just like a load command will load data, a store command will store the data.
- Reduce the cycles per instruction at the cost of the number of instructions per program.
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REDUCED INSTRUCTION SET ARCHITECTURE (RISC)

- Simpler instruction, (simple instruction decoding)
- Instruction comes undersize of one word
- Instruction takes a single clock cycle to get executed
- More general-purpose registers
- Simple Addressing Modes
- Fewer Data types
- A highly pipeline can be achieved
- Optimizes the performance by focusing on software

COMPLEX INSTRUCTION SET ARCHITECTURE (CISC)

The main idea is that a single instruction will do all loading, evaluating, and storing operations just like a multiplication command will do stuff like loading data, evaluating, and storing it, hence it’s complex.

The CISC approach attempts to minimize the number of instructions per program but at the cost of an increase in the number of cycles per instruction

COMPLEX INSTRUCTION SET COMPUTER (CISC)

- Complex instruction, (complex instruction decoding)
- Instructions are larger than one-word size
- Instruction may take more than a single clock cycle to get executed
- Less number of general-purpose registers as operations get performed in memory itself
- Complex Addressing Modes
- Less Instruction Pipeline
- Optimizes the performance by focusing on hardware

RISC VS. CISC

Reduced Instruction Set Computer (RISC)

- Used in: SPARC, ALPHA, Atmel AVR, etc.
- Few instructions (usually < 50)
- Only a few addressing modes
- Executes 1 instruction in 1 internal clock cycle (Tcyc)

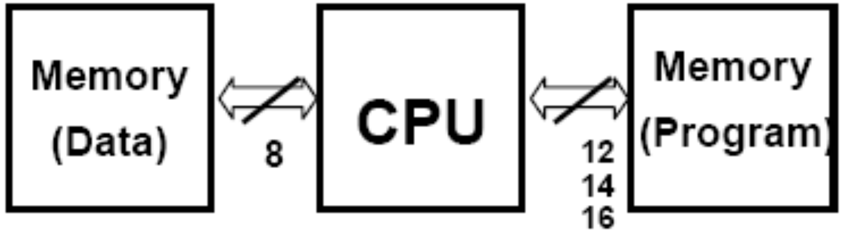
Complex Instruction Set Computer (CISC)

- Used in: 80x86, 8051, 68HC11, etc.
- Many instructions (usually > 100)
- Several addressing modes
- Usually takes more than 1 internal clock cycle (Tcyc) to execute

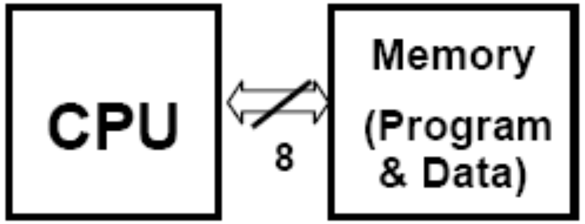
COMPUTER ARCHITECTURE

The architecture of any micro-controller or a micro-computer mainly refers to the overall arrangement of the constituent CPU

Harvard and Von Neumann architecture serve as the two major ways using which the microcontroller gets its CPU arrangement with the ROM and RAM



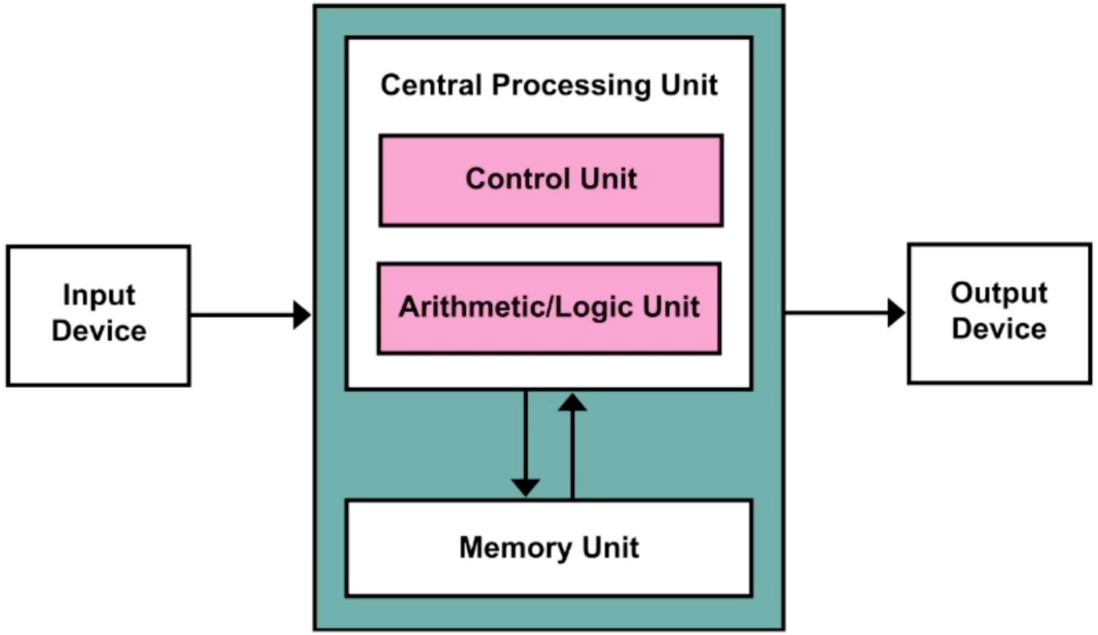
Harvard Architecture



Von–Neumann Architecture

VON NEUMANN ARCHITECTURE

- Memory holds both programs and data; this is also known as the stored program concept.
- Memory is addressed linearly; that is, there is a single sequential numeric address for each and every memory location.
- Memory is addressed by the location number without regard to the data contained within.
- Memory is split to small cells with the same size. Their ordinal numbers are called address numbers.



ADVANTAGES OF VON NEUMANN

Control Unit fetch data and instructions in the same way from one memory

It simplifies design and development of the Control Unit
Data from memory and from devices are accessed in the same way

Memory organization is in the hands of programmers

DISADVANTAGES OF VON NEUMANN

Serial instruction processing does not allow parallel execution of program

Parallel executions are simulated later by the Operating system

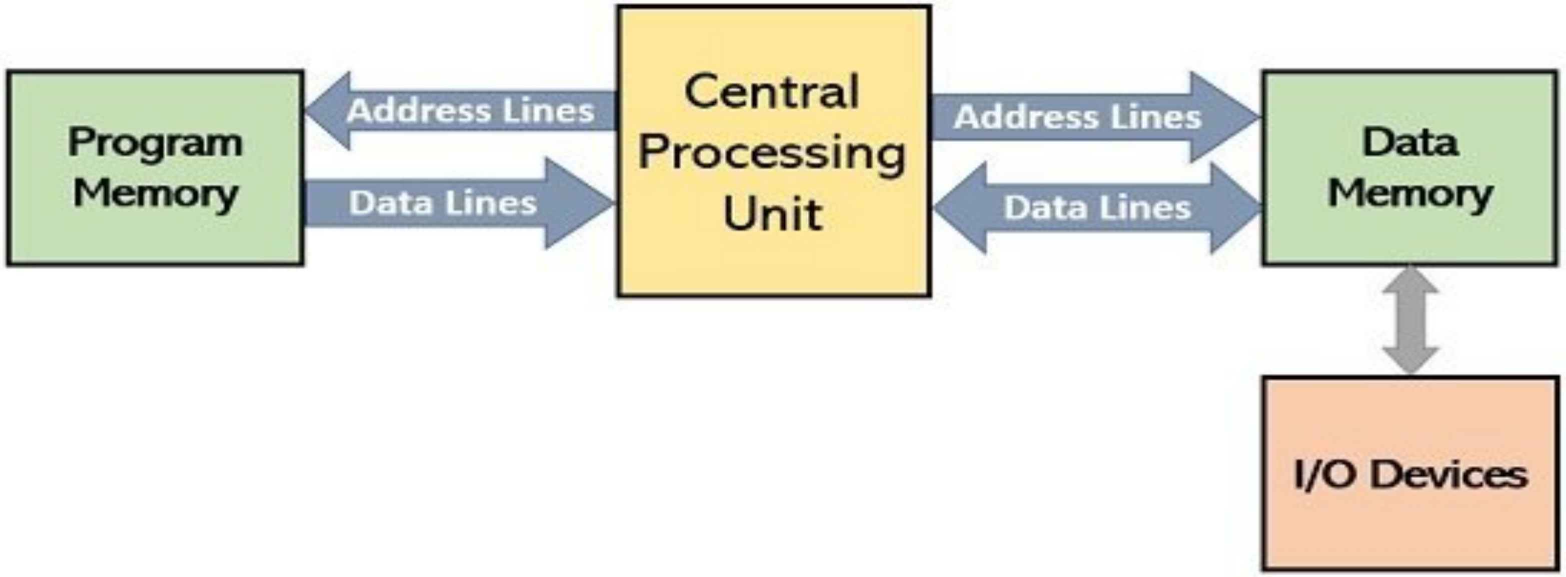
One bus is a bottleneck. Only one information can be accessed at the same time

HARVARD ARCHITECTURE

It is the computer architecture that contains separate storage and separate buses for instructions and data.

It is mainly developed to overcome Von-Neumann bottleneck.

The main advantage that the CPU can access instructions and read/write data at the same time.



ADVANTAGES OF HARVARD ARCHITECTURE

Since it has two memories, this allows parallel access to data and instructions

Data and instructions are accessed the same way
Both memories can use different cell sizes

DISADVANTAGES OF HARVARD ARCHITECTURE

Free data memory can’t be used for instruction and vice-versa

Production of a computer with two buses is more expensive

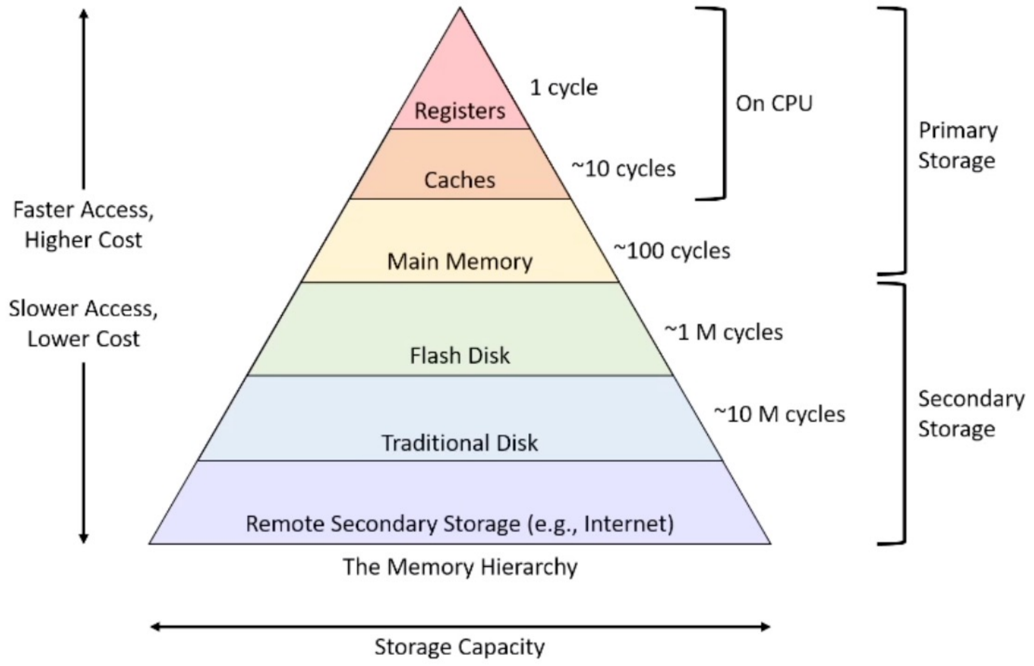
Development of the Control Unit is expensive and more complex

WHAT IS MEMORY?

Memories in computer are electronic components that stores data and program instructions.

Memories are characterized by:

- Access speed (read and write)
- Capacity
- Volatile or non-volatile



The Memory Hierarchy

VOLATILE VS. NON-VOLATILE MEMORY

Volatile memory stores data when a computer is on but erases it as soon as the computer is switched off

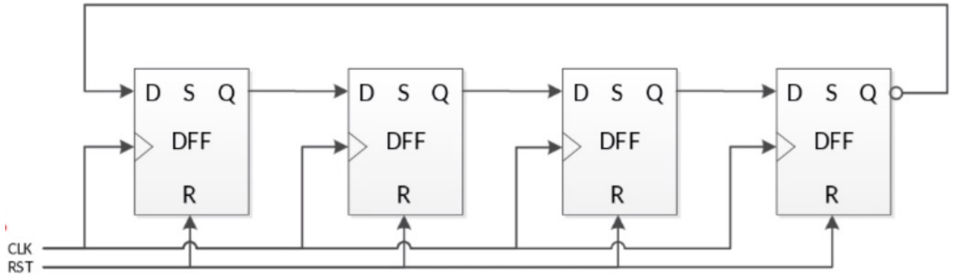
Whereas Non-volatile memory remains in a computer even after the system shuts off.

REGISTERS

A register is basically a storage space for units of memory that are used to transfer data for immediate use by the CPU for data processing.

Characteristics:

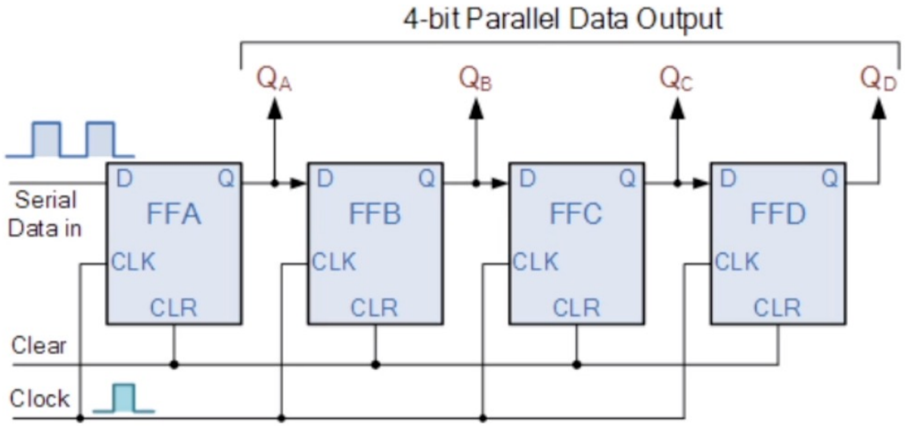
- The fastest memory
- Small capacity
- Some of them store addresses, instructions, or status



Flip-flops play a vital role in designing the most popular shift registers.

The set of Flip-flops is nothing but a register, used to store numerous data bits.

- A Flip-Flop stores only 1-bit
- 8-bit registers have 8 connected Flip-Flops



READ ONLY MEMORY (ROM)

It is a non-volatile and read only memory

Data stored in these chips is non-volatile

On turn on, the computer loads BIOS from ROM

Data stored in these chips is either unchangeable or requires a special operation to change

Applications: Video Games, Calculators, etc...

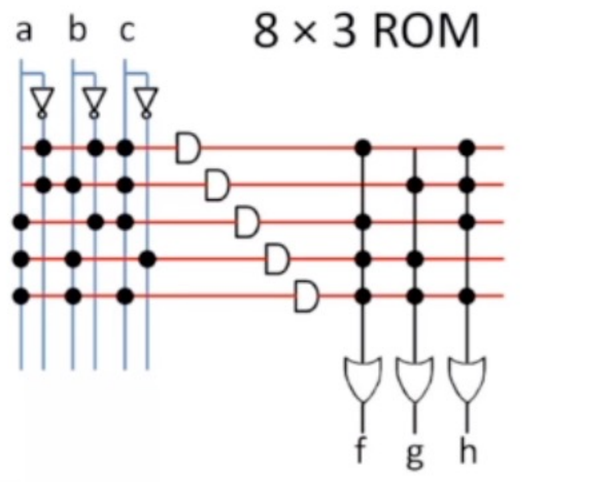
READ ONLY MEMORY (ROM)

It is non-volatile and read only memory.

ROM types:

- MROM:
  - Maskable ROM, and can not be programmed.
- PROM:
  - Programmable ROM, and can be programmed once.
- EPROM:
  - Erasable PROM, it can be erased using UV (Ultraviolet) and reprogrammed.
- EEPROM:
  - Electrically EPROM, it can be electrically erased and reprogrammed.
- Flash:
  - It is EEPROM with larger page size.

a	b	c	f	g	h
0	0	0	0	0	0
0	0	1	1	0	1
0	1	0	0	0	0
0	1	1	0	1	1
1	0	0	0	0	0
1	0	1	1	0	1
1	1	0	1	1	0
1	1	1	1	1	1



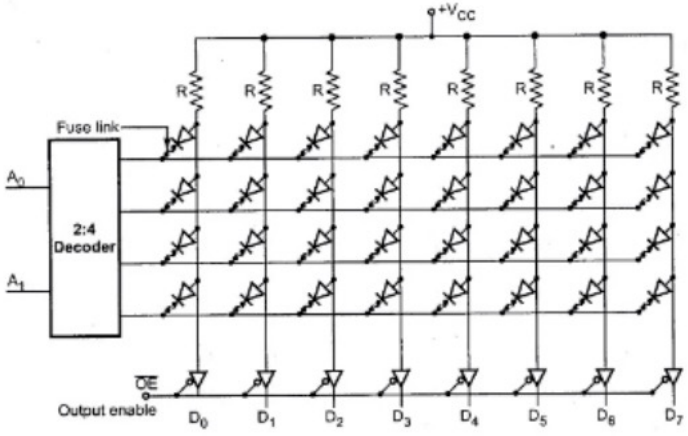
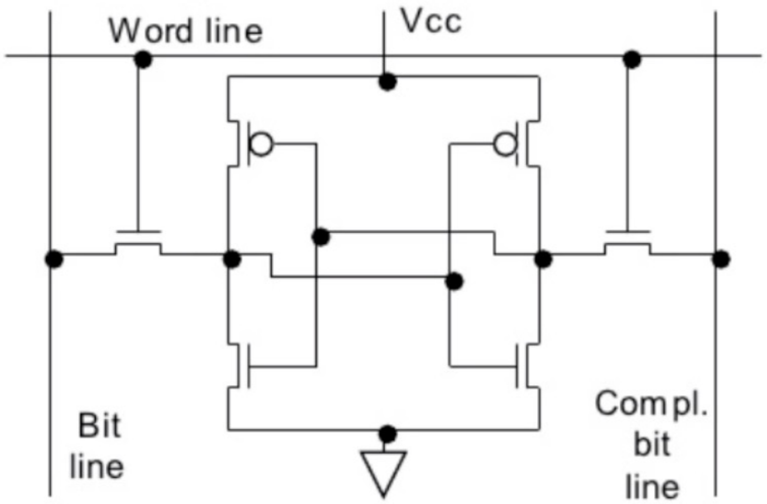


Fig. 3.71 Four byte PROM

RANDOM ACCESS MEMORY(RAM)

- It is volatile with read/write operations.
- Data is stored in transistors and requires a constant power flow
- Because of the continuous power, SRAM doesn't need to be
- refreshed to remember the data being stored
- SRAM is called static as no change or action i.e.; refreshing is not needed to keep the data intact
- It is used in cache memories

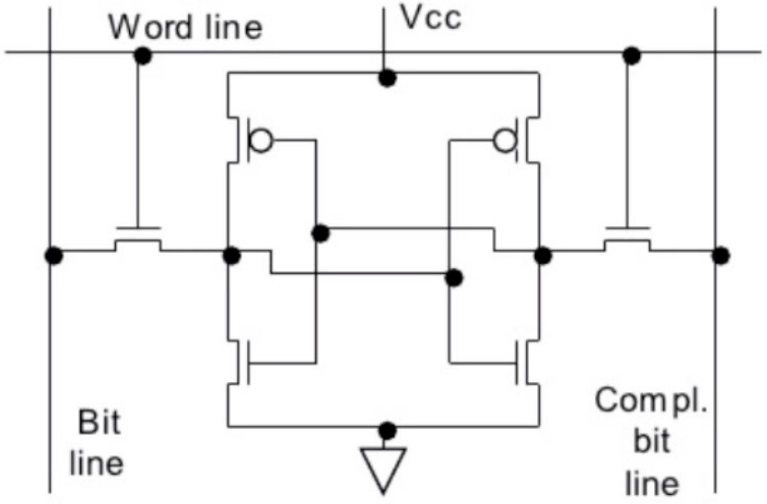


(b) Typical SRAM cell

ADVANTAGES OF SRAM

Faster access speed than DRAM
Can be used to create a speed-sensitive cache

Medium power consumption



(b) Typical SRAM cell

DISADVANTAGES OF SRAM

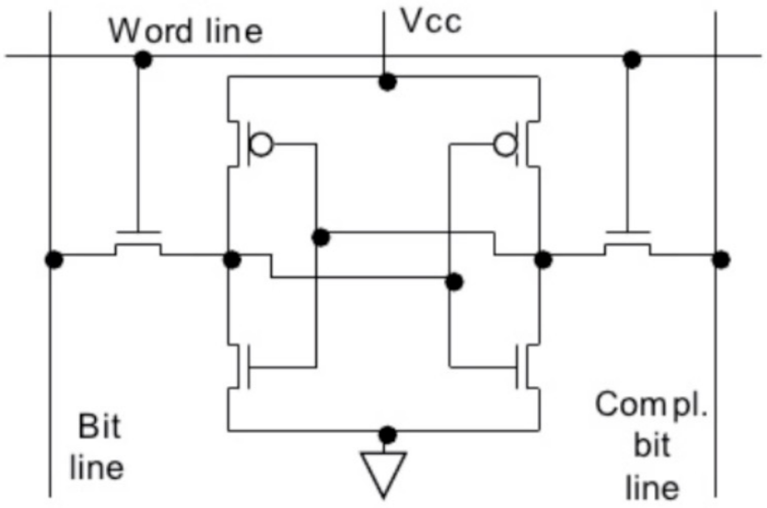
More expensive to manufacture than DRAM

Data can be lost if SRAM is not powered

Low storage capacity

More complex design compared to DRAM

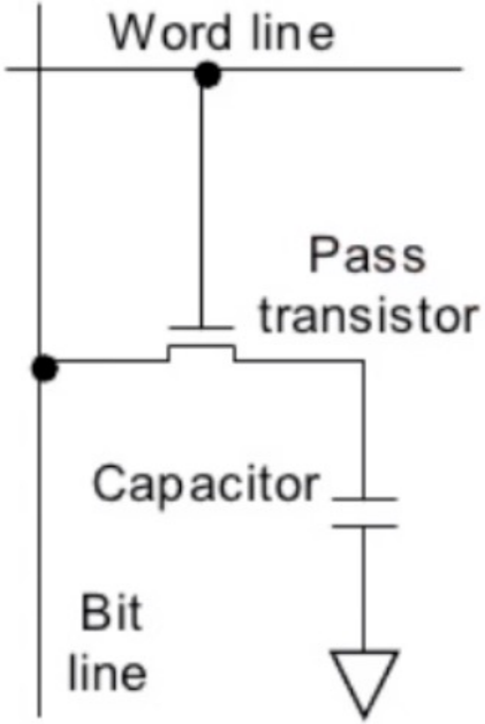
Takes up much more space than DRAM



(b) Typical SRAM cell

RANDOM ACCESS MEMORY(RAM)

- Data is stored in capacitors.
- Capacitor stores electric charge whose level represents a 1 or 0
- Capacitors dissipate with time and hence the charge must be restored frequently
- So, a periodic refresh of power is required in order to function every 64 ms
- DRAM is called dynamic as constant change or action(change is continuously happening) i.e. refreshing is needed to keep the data intact. It is used to implement main memory.



(a) DRAM cell

ADVANTAGES OF DRAM

More affordable than SRAM (Lower Cost)

Higher storage capacity

Offers a simple structure.

Utilizes logic and circuitry which makes the memory module simpler to setup and use.

DISADVANTAGES OF DRAM

DRAM is slower than SRAM
Lower access speeds
Consumes more power compared to SRAM

NON-VOLATILE RAM (NVRAM)

- It is a category of RAM that retains stored data even if the power is switched off (just an SRAM with a battery backup)
- When the power is turned on, the NVRAM operates just like any other SRAM □When the power is turned off, the NVRAM draws just enough power from the
- battery to retain its data
- NVRAM is common in embedded systems
- However, it is expensive--even more expensive than SRAM, because of the battery--so its applications are typically limited to the storage of a few hundred bytes of system-critical information that can't be stored in any better way.
- Types:
  o Battery-backed static RAM o Magneto resistive RAM
  o Ferroelectric RAM

ADVANTAGE OF NVRAM

Provides excellent performance when compared to other non-volatile memory products

Supports applications that need quick read or write operations using non-volatile memories, such as antilock braking systems and parallel processing controllers for local area networks.

Less power is required for NVRAMs, so the backup guarantee can be ensured for up to 10 years.

DISADVANTAGE OF NVRAM

NVRAM that requires a battery that will eventually need to have the battery replaced.

As information is re-written to flash memory, it deteriorates and will eventually no longer work.

THANKS