Lecture 1:
Introduction to Microcontroller

Embedded Systems

An embedded system is a smart system that consists of both hardware and software designed to perform a set of tasks.

Example of embedded system

Mobile phones. These consist of many embedded systems, including GUI software and hardware, operating systems (OSes), cameras, microphones, and USB (Universal Serial Bus) I/O (input/output) modules.

Microprocessor

Microprocessors are the core of any modern computer: they are single chip processing units responsible for computing each operation stored in the program.

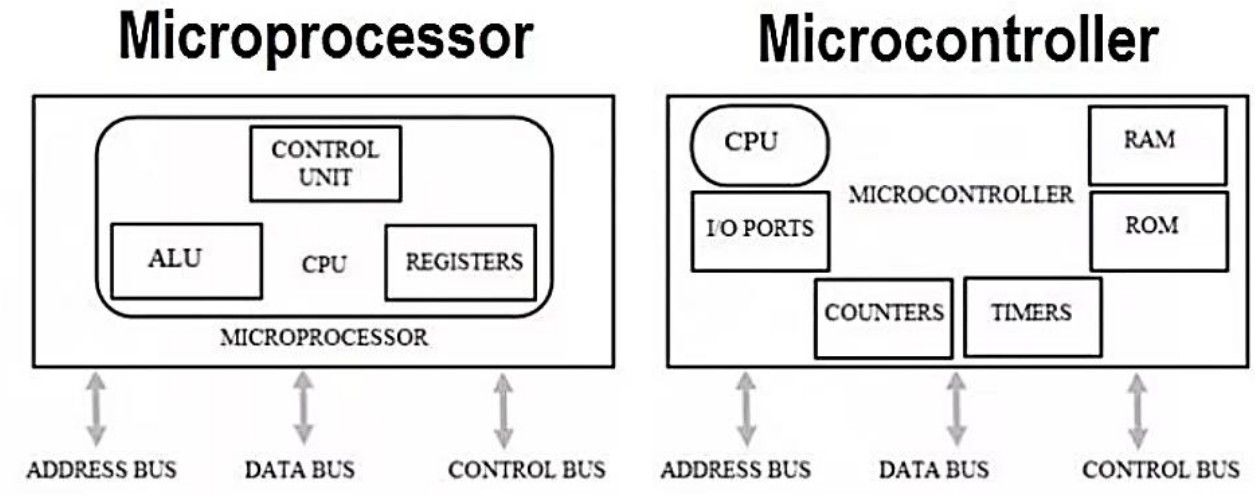
Microcontroller

A microcontroller is a small and low-cost microcomputer, which is designed to perform the specific tasks of embedded systems.

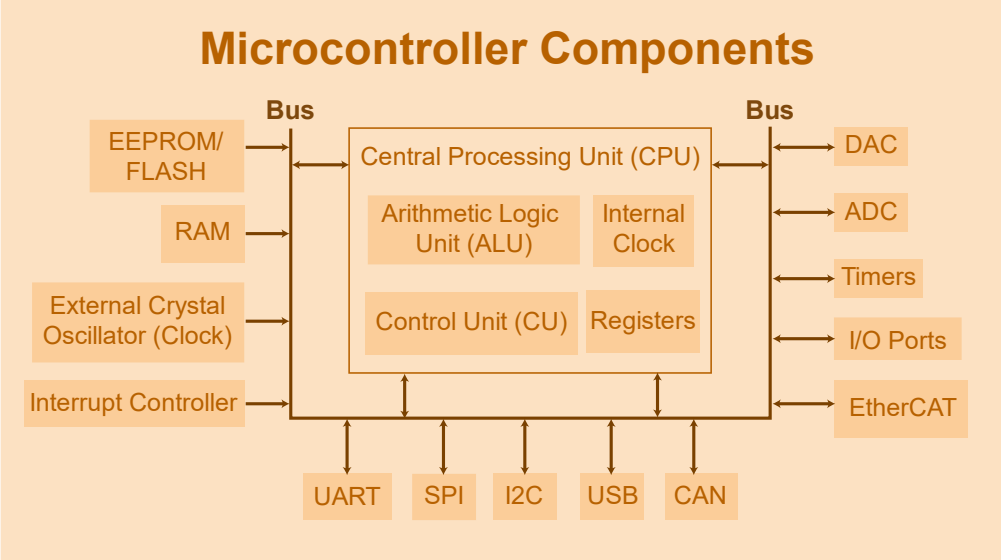
Microprocessors are different than microcontrollers in their design. Microprocessors have the only CPU inside them and no in-memory support while Microcontrollers, on the other side, has CPU, RAM, ROM and other peripherals which are all embedded on the chip.

Note:
We use the word "**peripheral**" to describe the hardware modules that help a microcontroller to interact with the external system.

Microprocessor	Microcontroller
Microprocessors are multitasking in nature. Can perform multiple tasks at a time. For example, on computer we can play music while writing text in text editor.	Single task oriented. For example, a washing machine is designed for washing clothes only.
RAM, ROM, I/O Ports, and Timers can be added externally and can vary in numbers.	RAM, ROM, I/O Ports, and Timers cannot be added externally. These components are to be embedded together on a chip and are fixed in numbers.
Designers can decide the number of memory or I/O ports needed.	Fixed number for memory or I/O makes a microcontroller ideal for a limited but specific task.
External support of external memory and I/O ports makes a microprocessor-based system heavier and costlier.	Microcontrollers are lightweight and cheaper than a microprocessor.
External devices require more space and their power consumption is higher.	A microcontroller-based system consumes less power and takes less space.



Microcontroller Components



Types of Memory

Three types of memories are commonly used in modern microcontrollers.

1. Random Access Memory (RAM)
2. Electrically Erasable Programmable Read-Only Memory (EEPROM)
3. Flash Memory

Random Access Memory (RAM)

- It is a **volatile** memory, which means it can only be accessed when the system is **powered-up**. As the system power shuts down, so do the contents inside the RAM.

- It has a **faster access time**, but this is also expensive when compared with the other ones. It is mainly used to store temporary data, variables, and constants during the execution of user instructions.

Electrically Erasable Programmable Read-Only Memory (EEPROM)

- It is a **non-volatile memory**, which means that contents in such a memory remain intact even when the power is removed.

- The main use of EEPROM in the microcontroller is to **store user instructions and data**. The microcontroller then accesses the instructions one-by-one and sequentially executes them.

Flash Memory

- Flash Memory is also **non-volatile memory**.

- Unlike EEPROM, it can only **program a whole sector** or block of bytes.

Some microcontroller manufacturers use either Flash or EEPROM, while others use both to provide more flexibility to the end-user.

Central Processing Unit (CPU)

CPU is a component of the microcontroller that fetches instructions from the memory, decodes them, and then executes them.

Control Unit

a control unit controls the operations of all parts of the computer **but it does not carry out any data processing operations**. Some main functions of the control unit are listed below:

- Controlling of data and transfer of data and instructions is done by the control unit among other parts of the computer.
- The control unit is responsible for managing all the units of the computer.
- The main task of the control unit is to obtain the instructions or data which is input from the memory unit, interprets them, and then directs the operation of the computer according to that.
- The control unit is responsible for communication with input and output devices for the transfer of data or results from memory.
- The control unit is **not responsible** for the processing of data or storing data.

ALU (Arithmetic Logic Unit)

ALU (Arithmetic Logic Unit) is responsible for performing arithmetic and logical functions or operations. It consists of two subsections, which are:

1. Arithmetic Section
2. Logic Section

Registers

- Registers are temporary storage areas within a CPU. They are used to store the information about the program flow, program status, instruction results, and the hardware configuration.
- They are much **faster to access** than the memory.
- This is the single main reason why CPU prefers registers over the memory for operations involving **immediate data access**.

Clock

You need a **Clock Signal** which can synchronize each activity of the CPU with a **rising or falling edge**. Moreover, the **frequency** of the clock signal will specify the **execution period** for each instruction. Higher the frequency, lower the execution time.

I/O Ports

- **Input-Output ports** in microcontroller to read dynamic user-inputs, or to control external devices.
- I/O Ports provide the user input data from input devices to the CPU.
- I/O Ports output the desired information to the user by interfacing with the LCD or LED display.

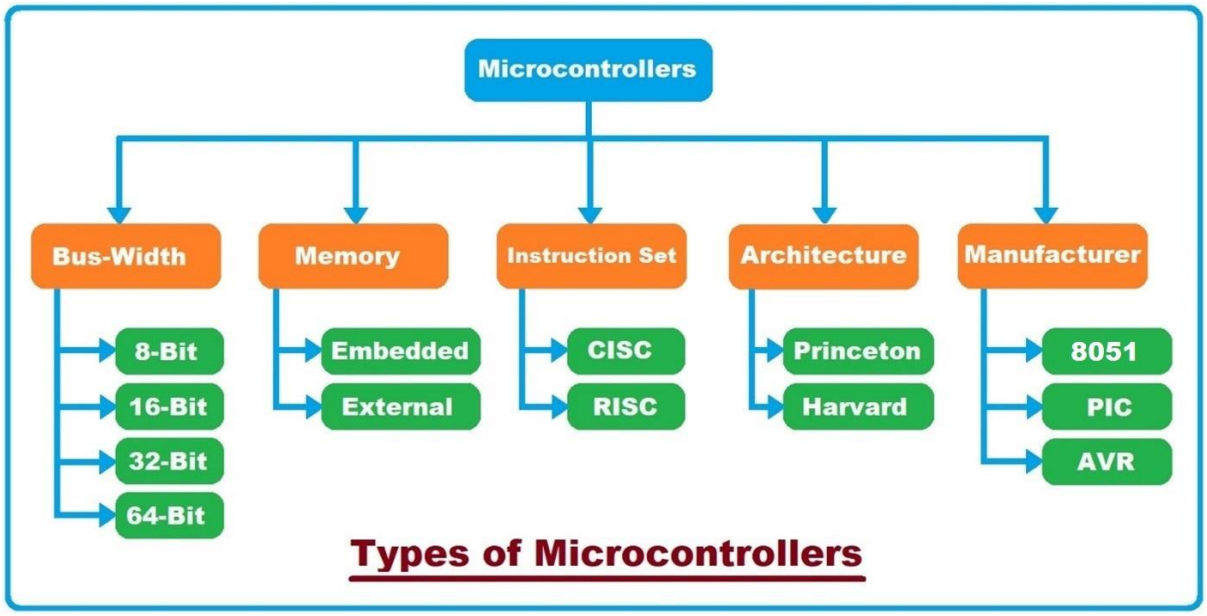
Each port in a microcontroller is programmable to be either input/output. This provides a user with the flexibility to program the **I/O ports** as per the application needs.

Bus

- The bus will establish a communication link between different components.
- There are three kinds of buses which are mostly used in microcontrollers:
  - **Instruction/Data Bus:** This bus helps transfer instructions/data back and forth into CPU and the memory
  - **Address Bus:** This bus specifies the address where the desired instruction/data are located inside the memory
  - **Control Bus:** This bus specifies whether the instructions/data are to be written or be fetched from the memory

Types of Microcontroller

There are different types of Microcontrollers available and are classified based on Bus-width, Memory, Insutruction Set, Architecture, and Manufacturer.



Microcontroller Types based on Bus-Width

Microcontrollers come in 8 bit, 16 bit, 32 bit and 64 bit.

- In an **8-bit** microcontroller, the point when the internal bus is 8-bit then the ALU performs the arithmetic and logic operations.
- The **16-bit** microcontroller performs greater precision and performance as compared to the 8-bit.
- The **32-bit** microcontroller uses the 32-bit instructions to perform the arithmetic and logic operations. These are used in automatically controlled devices including implantable medical devices, engine control systems, office machines, appliances, and other types of embedded systems.

Microcontroller Types based on Memory

Based on memory, microcontrollers are divided into two types: **external memory** microcontrollers and **embedded memory** microcontrollers.

- **External Memory**

  In the case of external memory microcontrollers, memory is not interfaced within the microcontroller. Rather, the user needs to **connect an external memory** to store instructions/data.

- **Embedded Memory**

  For embedded memory microcontrollers, memory is **embedded** inside the microcontroller.

Microcontroller Types based on the Instruction set

Based on instruction set, microcontrollers are classified into two types i.e CISC-CISC and RISC-RISC.

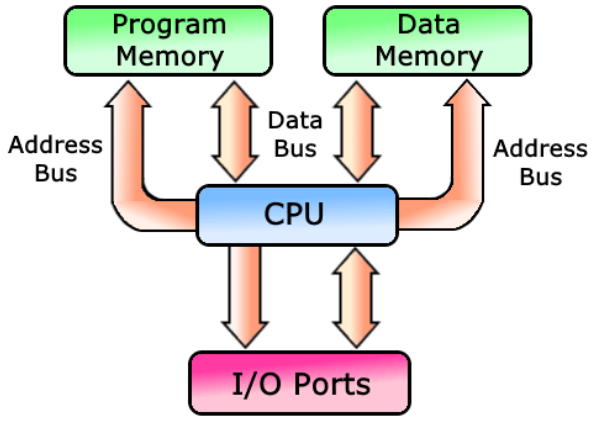
- **complex instruction set computer (CISC)**: CISC computers have small programs. It has a huge number of compound instructions, which takes a long time to perform.
- **reduced instruction set computer (RISC):** RISC is a computer that only uses simple commands that can be divided into several instructions that achieve low-level operation within a single CLK cycle.

RISC is an alternative to the CISC architecture and is often considered the most efficient CPU architecture technology available today.

Microcontroller Types based on the Architecture

Harvard Architecture Microcontroller:

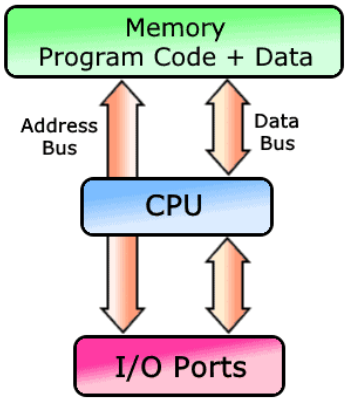
The Harvard architecture based microcontroller has physically separate memory storage for program code (instructions) and the data. Thus, they have separate bus lines and can be accessed both at the same time. Therefore, the Harvard architecture based microcontroller can complete instruction in one machine cycle.



Harvard Architecture

Von Neumann (or Princeton) Architecture Microcontroller:

Von Neumann or Princeton architecture suggests using a single memory for both the program and data storage. It is the most used architecture in all computers, desktop and laptops to date.



Von Neumann Architecture

There is only one bus required for accessing data and fetching instructions. Thus, both operations cannot be done at the same time and they must be scheduled. This is why von Neumann architecture based microcontroller takes two machine cycles to complete an instruction. Since it uses a single bus system, its design is simple and production is very low compared to Harvard architecture.

	Von Neumann Architecture	**Harvard Architecture**
1	Here the RAM and ROM is not separated, and a single memory connection is given to CPU.	Here the CPU is connected separately with the RAM and ROM .
2	Less space is required	More space is required.
3	Speed is somewhat low because there is the bottleneck problem and fetching data and instruction at the same time is unable. At a time, it can fetch either data or instruction.	Speed is faster because it takes less time to fetch data and instructions at the same time from the 2 memories called instruction memory and the data memory.
4	There is a common bus for transferring instruction and data.	There are separate busses to transfer instruction and data.
5	Used in personal computers and the small sized computers.	This architecture is used in signal processing and the micro controllers.
6	This computer architecture is based on stored program computer concept which is a traditional one.	This computer architecture is based on Harvard Mark I Relay based model which is a modern one.
7	Same memory address is used for both instructions and data.	Separate physical memory addresses are used for both instructions and data.
8	Here the two clock cycles are needed to execute a single instruction.	A single clock cycle is needed to execute an instruction.
9	Instructions and read/write operations cannot be accessed by the cpu at the same time.	CPU can access both instructions and write/read operations at the same time.
10	These architecture-based computers are somewhat cheaper than Harvard architecture.	This is expensive than Von Neumann architecture.

Microcontroller Types based on the Manufacture

8051 Microcontroller

PIC (Programmable Interface Controllers) Microcontroller

AVR Microcontroller

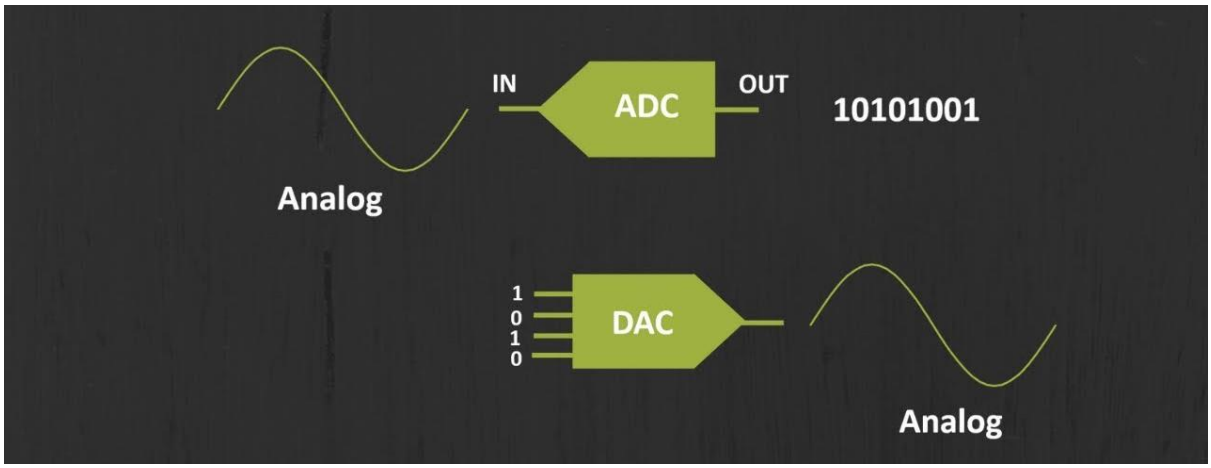
It is an electronic chip which is manufactured by Atmel. This microcontroller is the advanced version of a microcontroller. This microcontroller is used for high-speed signal processing operation which is connected inside an embedded system.

Analog-to-Digital Converter (ADC)

ADC takes Analog inputs and converts them to digital values. These digital values are then fed into CPU for further processing.

Digital-to-Analog Converter (DAC)

Digital-to-Analog Converter (DAC) converts digital pulses into Analog signals.



Microcontroller Applications

- **Baby Monitors**
- **Fire Detection**
- **Internet of Things**
- **Home Automation**
- **Light Sensing**
- **LED Control**
- **Low-Cost Wearables**
- **Medical Equipment**
- **Sub-Marines**
- **Ships**
- **Aerospace System**
- **and many more…**