Embedded Systems

Chapter two

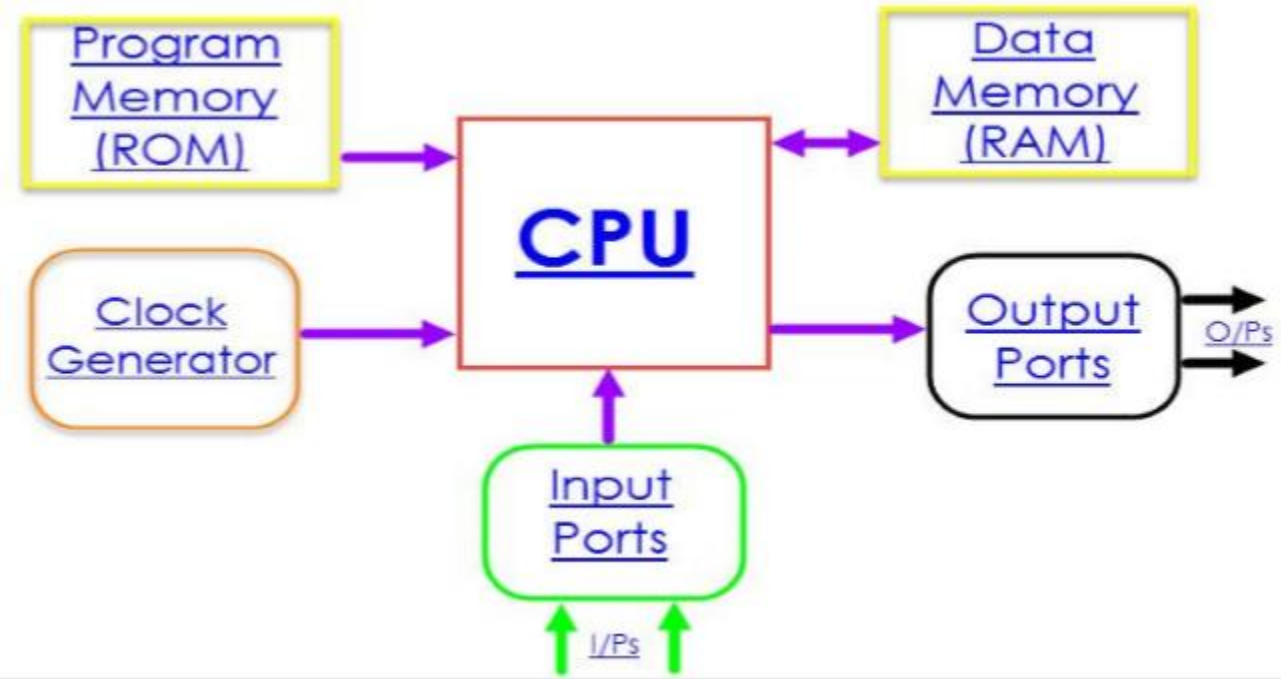
Lecture 11: Embedded Microcontrollers

Chapter II: Embedded Microcontrollers

- Introduction
- Structure of Basic Computer System
- Inside the Microcontroller
- Inside Embedded System
- CPU Families used in Microcontrollers
- AVR, ARM, 8051 and PIC Microcontrollers
- Criteria for Choosing Microcontrollers

Introduction

- A microcontroller(μC or MCU) is a compact integrated circuit designed to govern a specific operation in an embedded system.
- A typical microcontroller includes a processor, memory and input/output (I/O) peripherals on a single chip.
- Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications.



Elements of Microcontroller

A. The processor(CPU)-- A processor can be thought of as the brain of the device.

- It processes and responds to various instructions that direct the microcontroller's function.
- This involves performing basic arithmetic and logic unit and I/O operations.
- It also performs data transfer operations, which communicate commands to other components in the larger embedded system.

B. Memory-- A microcontroller's memory is used to store the data that the processor receives and uses to respond to instructions that it's been programmed to carry out.

- A microcontroller has two main memory types:.

1. **Program memory(ROM)**, which stores long-term information about the instructions that the CPU carries out.

- ✓ Program memory is non-volatile memory, meaning it holds information over time without needing a power source.
- ✓ Used to store program

1. **Data memory(RAM),** which is required for temporary data storage while the instructions are being executed.

- ✓ Data memory is volatile, meaning the data it holds is temporary and is only maintained if the device is connected to a power source

C. I/O peripherals: The input and output devices are the interface for the processor to the outside world.

- ✓ The input ports receive information and send it to the processor in the form of binary data.
- ✓ The processor receives that data and sends the necessary instructions to output devices that execute tasks external to the microcontroller

Other supporting elements of a microcontroller include:

- Analog to Digital Converter (ADC)-- An ADC is a circuit that converts analog signals to digital signals.
- ✓ It allows the processor at the center of the microcontroller to interface with external analog devices, such as sensors.
- Digital to Analog Converter (DAC)-- A DAC performs the inverse function of an ADC and allows the processor at the center of the microcontroller to communicate its outgoing signals to external analog components.
- System bus-- The system bus is the connective wire that links all components of the microcontroller together.
- Serial port-- The serial port is one example of an I/O port that allows the microcontroller to connect to external components.
- ✓ It has a similar function to a USB or a parallel port but differs in the way it exchanges bits.

Microcontroller Features

- A microcontroller's processor will vary by application.
- Options range from the simple 4bit, 8-bit or 16-bit processors to more complex 32-bit or 64-bit processors.
- Generally, microcontrollers are designed to be readily usable without additional computing components because they are designed with sufficient onboard memory as well as offering pins for general I/O operations, so they can directly interface with sensors and other components.

Microcontroller Features cont…

- When they first became available, microcontrollers solely used assembly language.
- Today, the C programming language is a popular option.
- Other common microprocessor languages include JavaScript.
- MCUs feature input and output pins to implement peripheral functions.
- Such functions include analog-to-digital converters, liquid crystal display (LCD) controllers, real-time clock (RTC) and universal serial bus (USB) connectivity.

- Sensors gathering data and attached to microcontrollers.

Types of Computer Architecture

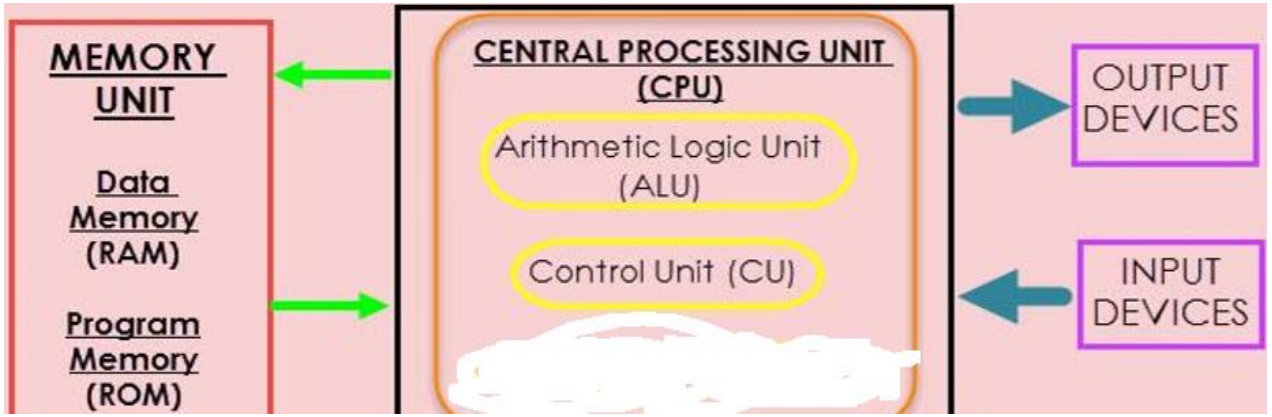
- Basically, Microprocessors or Microcontrollers are classified based on the two types of Computer Architecture: Von Neumann Architecture and Harvard Architecture.

Von Neumann Architecture

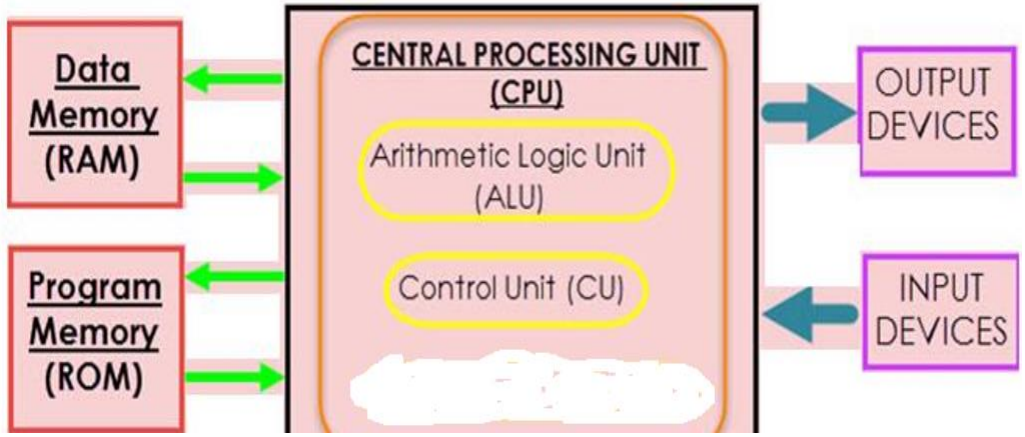
- Von Neumann Architecture or Princeton Architecture is a Computer Architecture, where the Program i.e. the Instructions and the Data are stored in a single memory.
- Since the Instruction Memory and the Data Memory are the same, the Processor or CPU cannot access both Instructions and Data at the same time as they use a single bus.
- This type of architecture has severe limitations to the performance of the system as it creates a bottleneck(complex) while accessing the memory.

Harvard Architectur

- In contrast to Von Neumann Architecture, uses separate memory for Instruction (Program) and Data.
- Since the Instruction Memory and Data Memory are separate in a Harvard Architecture, their signal paths i.e. buses are also different and hence, the CPU can access both Instructions and Data at the same time



Von Neumann Architecture



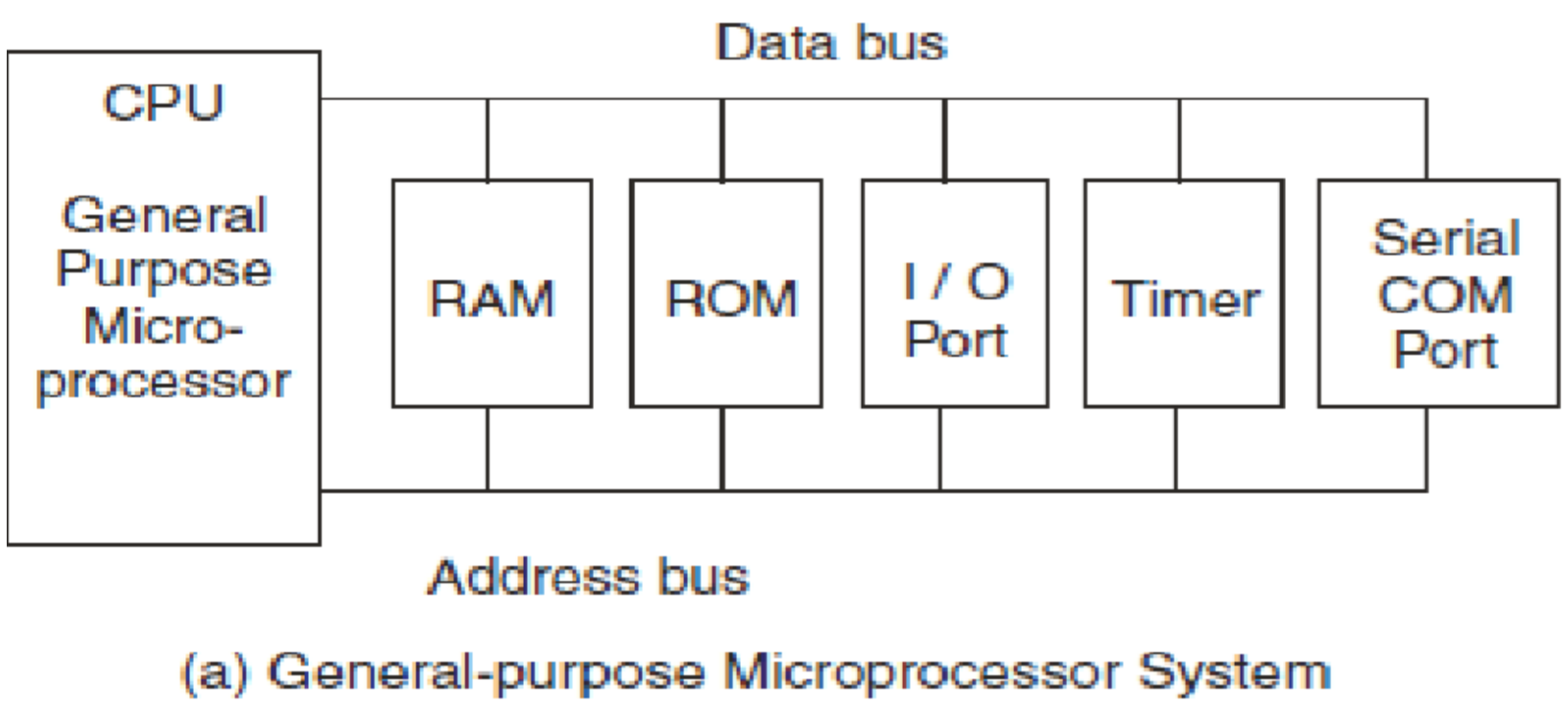
Harvard Architectur

Microcontroller Applications

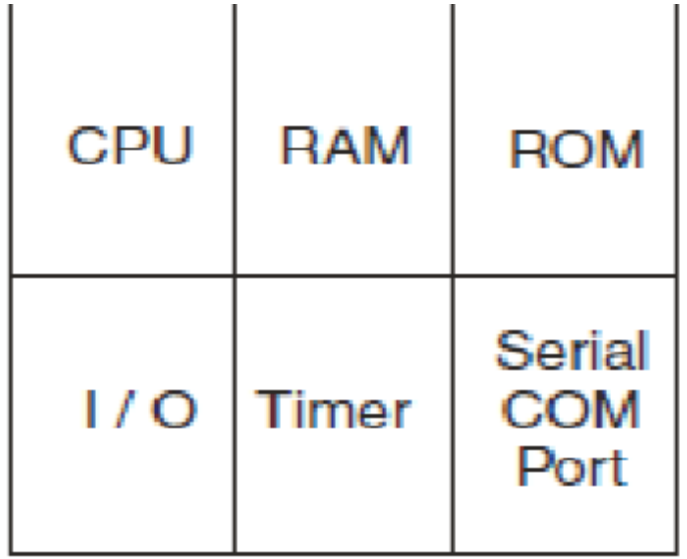
- Microcontrollers are used in multiple industries and applications, including in the home and enterprise, building automation, manufacturing, robotics, automotive, lighting, smart energy, industrial automation, communications and internet of things (IoT) deployments.
- They are also common in office machines such as photocopiers, scanners, fax machines and printers, as well as Smart meters, ATMs and security systems.
- In medical scenarios, microcontrollers can regulate the operations of an artificial heart, kidney or other organs.

Microcontrollers Vs. Microprocessors

- Microcontrollers are less expensive and use less power than microprocessors.
- Microprocessors do not have built-in RAM, read-only memory (ROM) or other peripherals on the chip, but rather attach to these with their pins.
- A microprocessor can be considered the heart of a computer system, whereas a microcontroller can be considered the heart of an embedded system.



(a) General-purpose Microprocessor System



(b) Microcontroller

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.

Internal Components of a Computer

- The internal components of a computer system consist of the hardware required to store and process data, and communicate with external, peripheral devices.
- The main internal components of a computer system are:
  - Processor
  - Main memory
  - Input/output (I/O) controllers
- These components are connected by the system bus, which is made up of the address bus, data bus, and control bus.
- Other types of memory are essential for the operation of a computer system.
- Secondary storage (e.g. hard disk, flash) provides permanent storage for programs and data.

Internal Components of a Computer

The processor

- The processor, sometimes referred to as the CPU (central processing unit), is the part of the computer that processes data by executing program instructions.
- For the processor to be able to execute a program, the program instructions need to be transferred from secondary storage into main memory from where they can be fetched, decoded, and executed.
- The data that needs to be processed is also loaded into main memory (from secondary storage) or provided by the input and output devices via the I/O controllers.

Main Memory

- Main memory is memory that can be accessed directly by the processor.
- Each memory location, where instructions or data are stored as binary sequences, has a physical address, which is a number used to locate that memory location and access its contents.
- There are two main types of main memory:
  - **RAM, which is the working memory that is used by the processor during the fetch-decode-execute cycle**
  - **ROM, which is used in the boot process for the computer system**
- Main memory is distinct from secondary storage, which the processor can't work with directly.
- Secondary storage must be accessed through I/O controllers.

Input/Output (I/O) Controllers

- All external (peripheral) devices are connected to the processor through I/O controllers.

  These provide the mechanism for:

  - input data to be received for processing from input devices, such as keyboards
  - the results of computation to be output from the system to output devices, such as display screens

- Secondary storage devices are also connected to the processor through I/O controllers.
- Secondary storage, in contrast to main memory, cannot be accessed directly by the processor.
- I/O controllers provide a set of addressable registers that the processor (CPU) can access to communicate with the I/O devices.

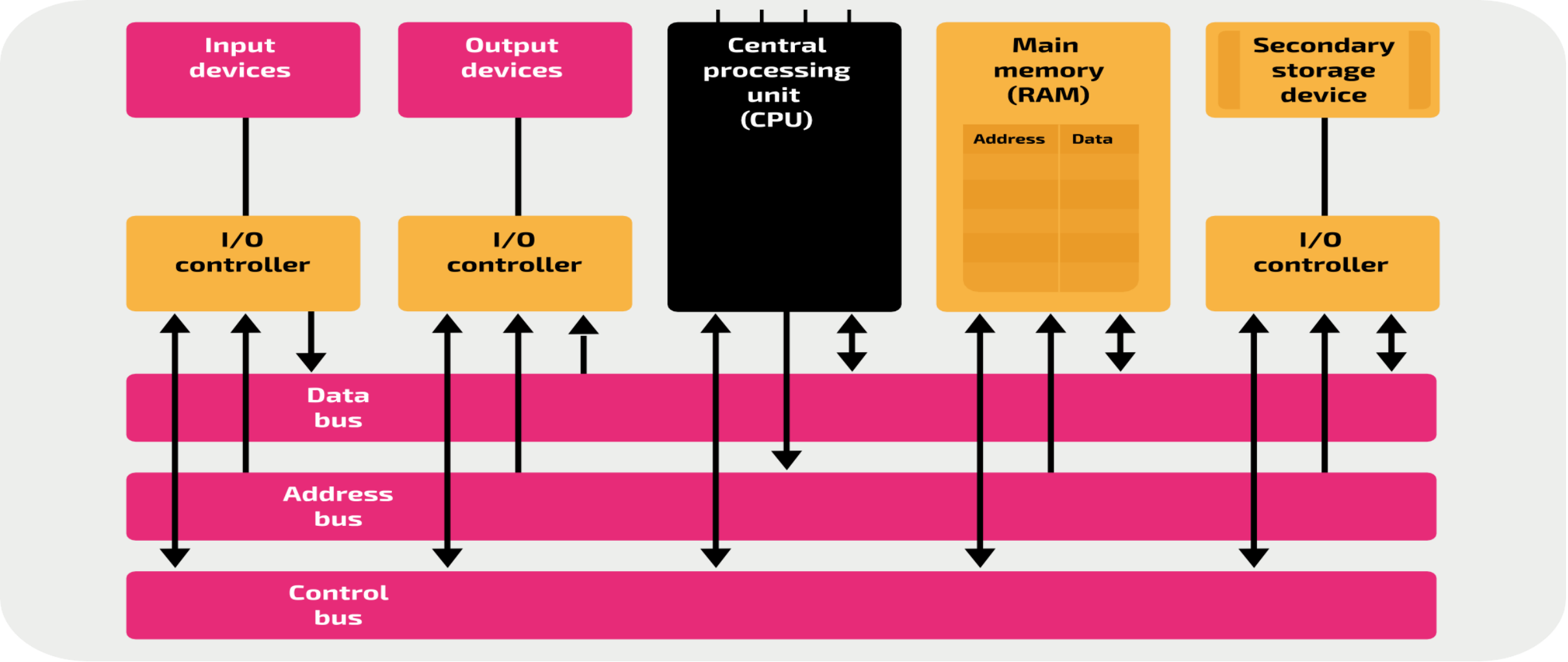
Buses

- The components of a computer system are connected together using buses.
- A bus is a communication system that is used to transfer data between components.
  - The system bus is a set of parallel connections that allow internal components to communicate with each other and exchange data.
  - There are also external buses that are used to connect the peripherals to the processor.

A model of the system bus

- The system bus is used to connect the processor (CPU), main memory, and the I/O controllers.
- The system bus is made up of:
  - an address bus
  - a data bus, and
  - a control bus

The following diagram illustrates an abstract model of the connections.



Data bus

- The data bus is used to transfer data and instructions.
- The data bus is bidirectional, i.e. it allows a two-way connection between internal components of the system allowing values to be written to or read from a location.
  - Data is transferred to and from the processor
  - Data is transferred to and from main memory
  - Data is transferred to and from the I/O controllers
- Instructions are carried from main memory into the processor (to be decoded and executed)
- The width of the data bus refers to its number of parallel lines. This determines the number of bits that can be transferred in one operation.
- For example, how many bits can be transferred in one go between the memory and the processor. It is typically a multiple of a byte (e.g. 8, 16, 32, or 64bits).
- If the width of the data bus is expressed as n bits, then n bits can be transferred at one time.
- The amount of data that can be fetched at one time can affect the processor performance.

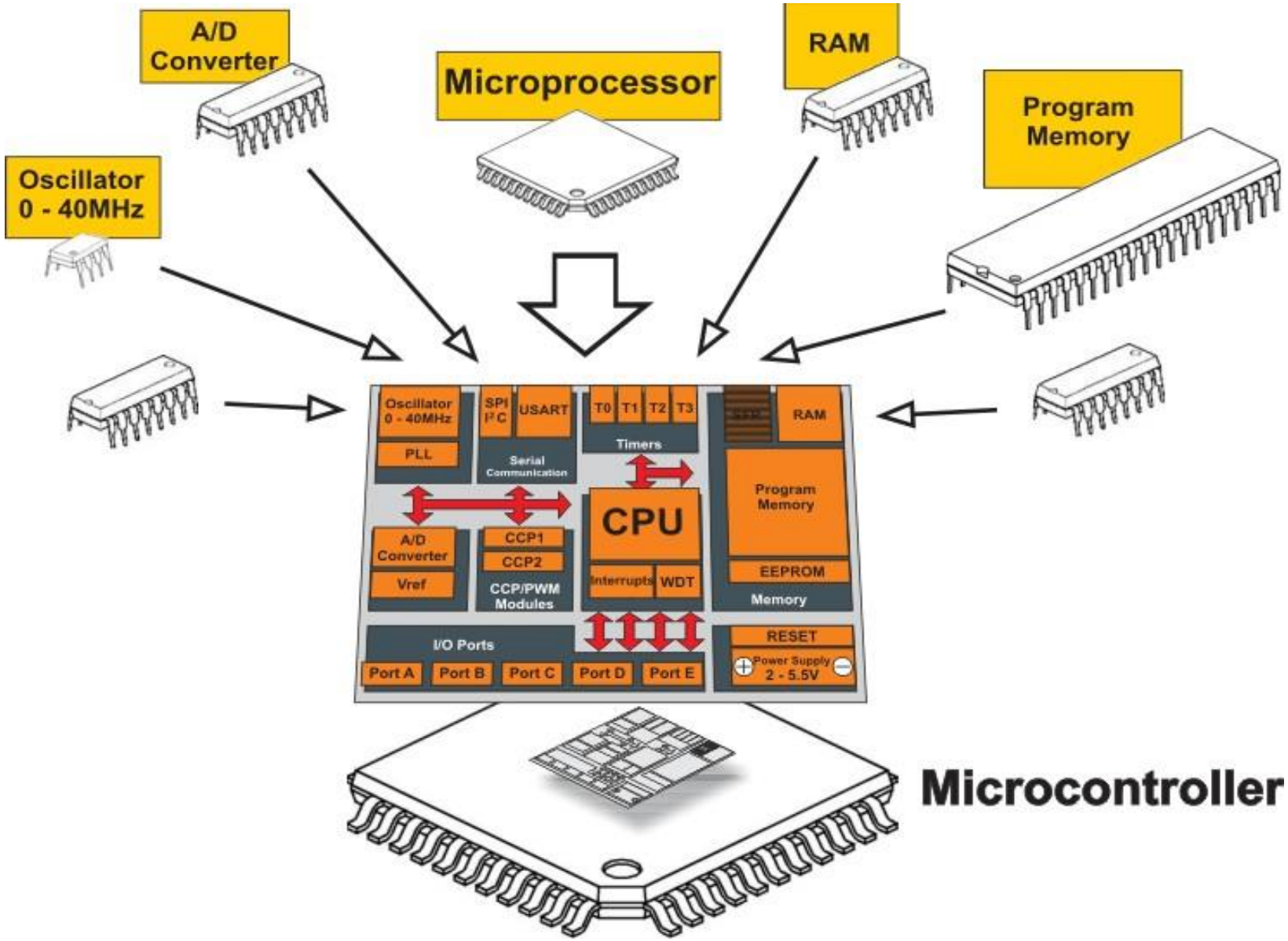
Address bus

- The address bus is used to specify the address of a memory location to either read (i.e. load) data from or write (i.e. store) data to that memory location.
- There is a one-way connection from the processor to the address bus and a one-way connection from the address bus to the main memory and to the I/O controllers.
- This is because the address bus is a unidirectional bus, which allows the processor to establish a connection with an addressable 'unit', whether it's a memory location or an I/O controller.

Control bus

- The control bus is used to send control signals that manage the operations that take place inside a computer system.
- This includes exchanging status signals between the components of the computer system, and transmitting clock signals required for the coordination of operations.
- For example, a control signal can be used to:
  - Request communication between two units
  - Specify the type of data that is being transferred via the other buses (i.e. data values, instructions, or addresses)
  - Synchronize the communication between the components using the clock pulses
- The control bus is bidirectional, i.e. there are two-way connections between the components that the control bus connects.

Inside Microcontroller



Inside the Embedded System

- CPU:
- Memory:
- Peripherals: are used to communicate with the outside world.

The main types of peripherals that are used include:

- Serial outputs: These are interfaces that send or receive data using one or two pins in a serial mode. They are less complex to connect but are more complicated to program.
- Analogue values: While processors operate in the digital domain, the natural world does not and tends to orientate to analogue values.
- Displays: Displays are becoming important and can vary from simple. LEDs and seven segment displays to small alpha-numeric LCD panels.
- Time derived outputs: Timers and counters are probably the most commonly used functions within an embedded system.

Software: The software components within an embedded system often encompasses the technology that adds value to the system and defines what it does and how well it does it.

The software can consist of several different components:

- Initialization and configuration
- Operating system or run-time environment
- The applications software itself

Some types of microcontrollers

- AVR(**A**lf and **V**egard's **R**ISC processor)
- ARM(Advanced RISC Machine)
- 8051
- PIC Microcontrollers

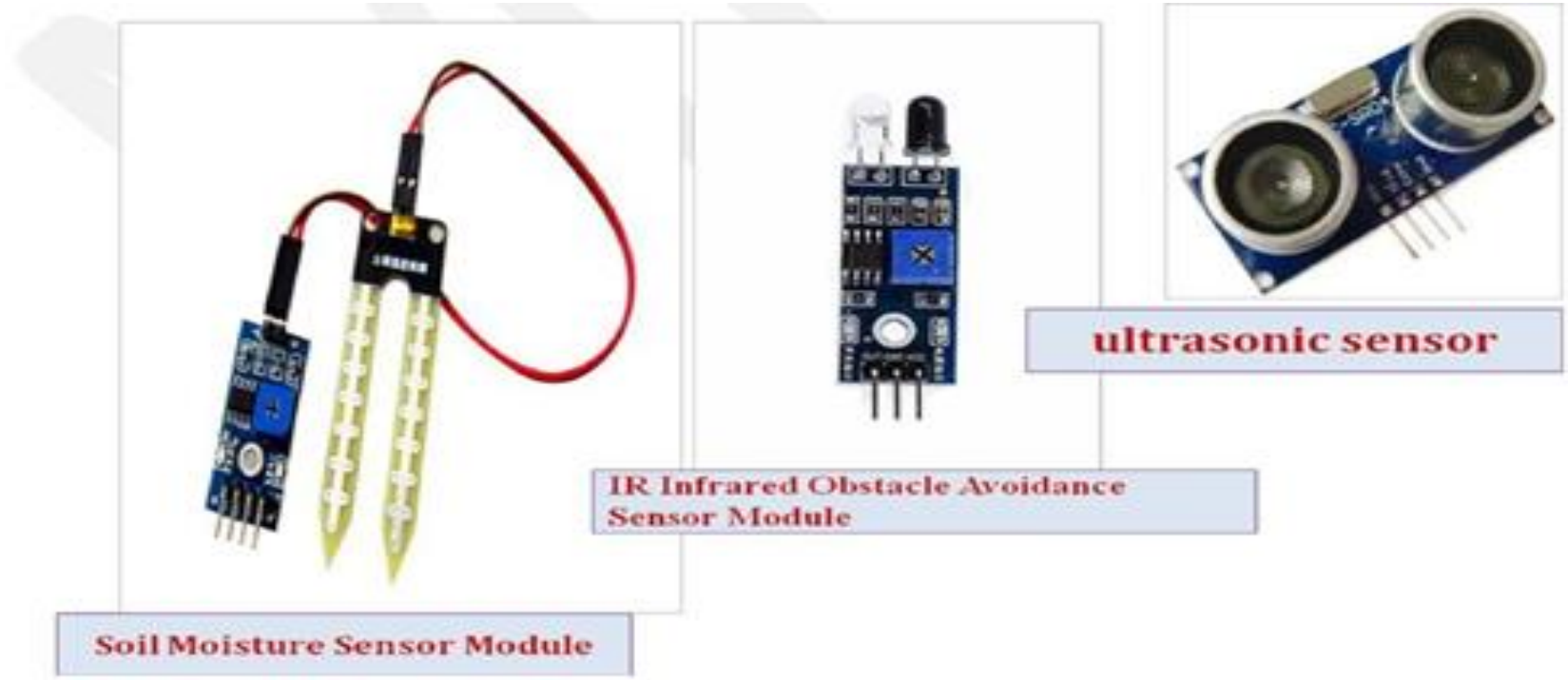
Sensors & Actuators

- Embedded system is in constant interaction with the real world
- Controlling/monitoring functions executed by the embedded system is achieved in accordance with the changes happening to the Real World.
- The changes in the system environment or variables are detected by the sensors connected to the input port of the embedded system.
- If the embedded system is designed for any controlling purpose, the system will produce some changes in controlling variable to bring the controlled variable to the desired value.
- It is achieved through an actuator connected to the out port of the embedded system.

Sensor

- A transducer device which converts energy from one form to another for any measurement or control purpose.
- Sensors acts as input device

Example: humidity sensor , ultrasonic, smoke sensors



Actuator

- A form of transducer device (mechanical or electrical) which converts signals to corresponding physical action (motion).

- Actuator acts as an output device

Eg. motor actuator which adjusts the position, valve

Individual assignment

1. *Read and write short note about the differences between 8051, ARM, AVR, And PIC Microcontrollers and their unique features.*
2. what is the difference between Reduced Instruction Set Architecture (RISC) and Complex Instruction Set Architecture (CISC)