Misr University for Science & Technology
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Department of Computer Science

Embedded System

AI 230 / AI 302

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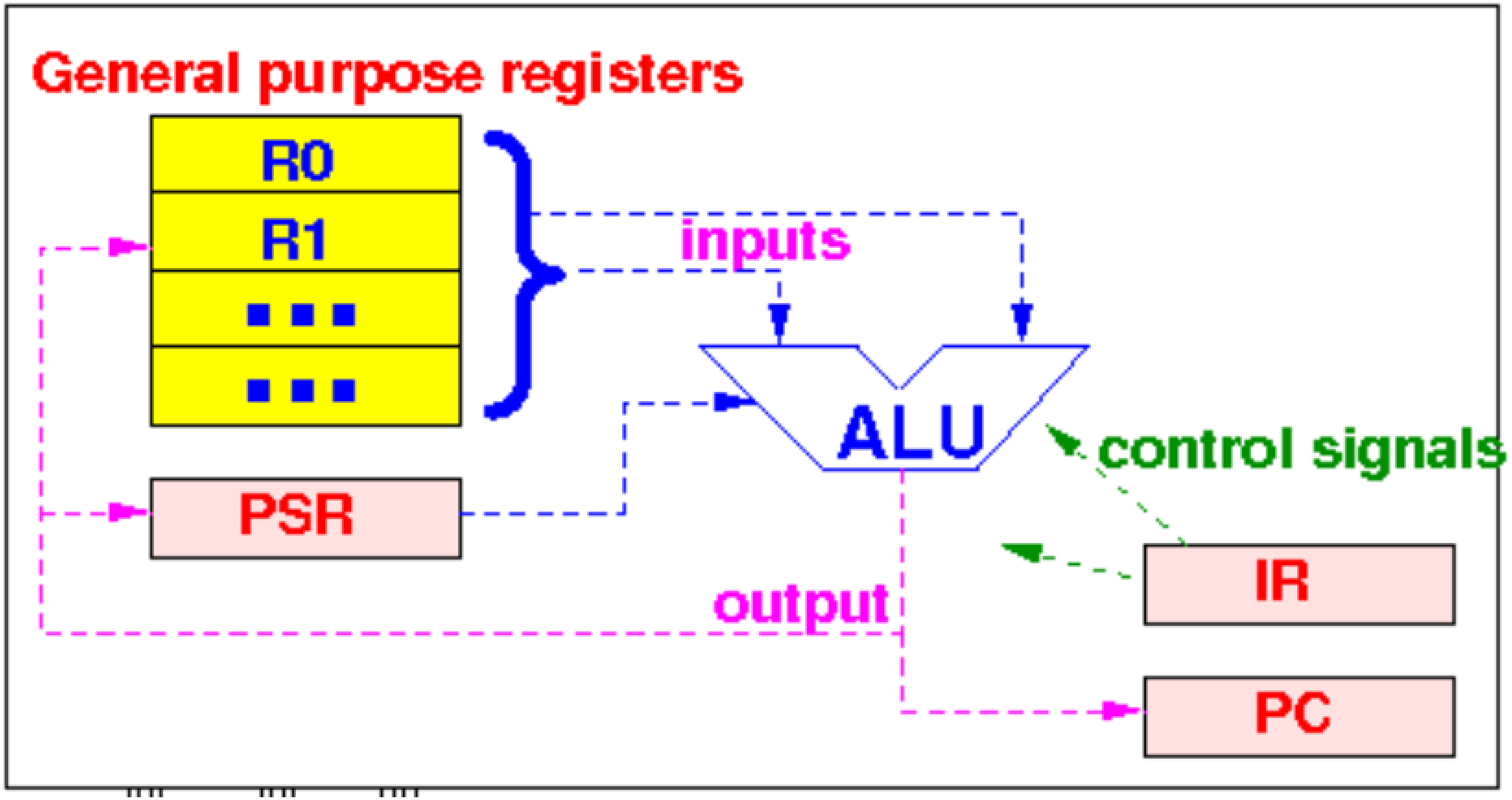
CPU Register Set

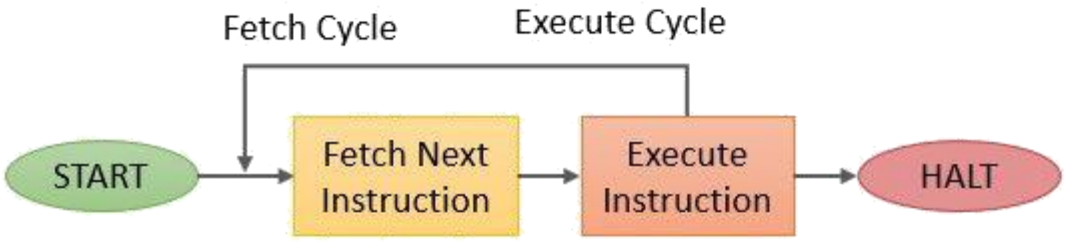
- Registers can be categorized based on their specific functions. Some common types of registers include:
  - **General-purpose** registers are used for any purpose, hence the name general purpose.
  - Used for various purposes, such as storing operands or results.
  - **Special-purpose** registers have specific functions within the CPU.
    - **Program Counter (PC):** Holds the address of the next instruction to be executed.
    - **Instruction Register (IR)**: Stores the current instruction being executed.
    - **Memory Address Register (MAR):** Holds the address of a memory location to be read from or written to.
    - **Memory Data Register (MDR):** Temporarily stores data being transferred to or from memory.
    - **Accumulator (ACC):** Stores intermediate results of arithmetic and logic operations.

CPU Register Set



CPU Register Set (Special-purpose)

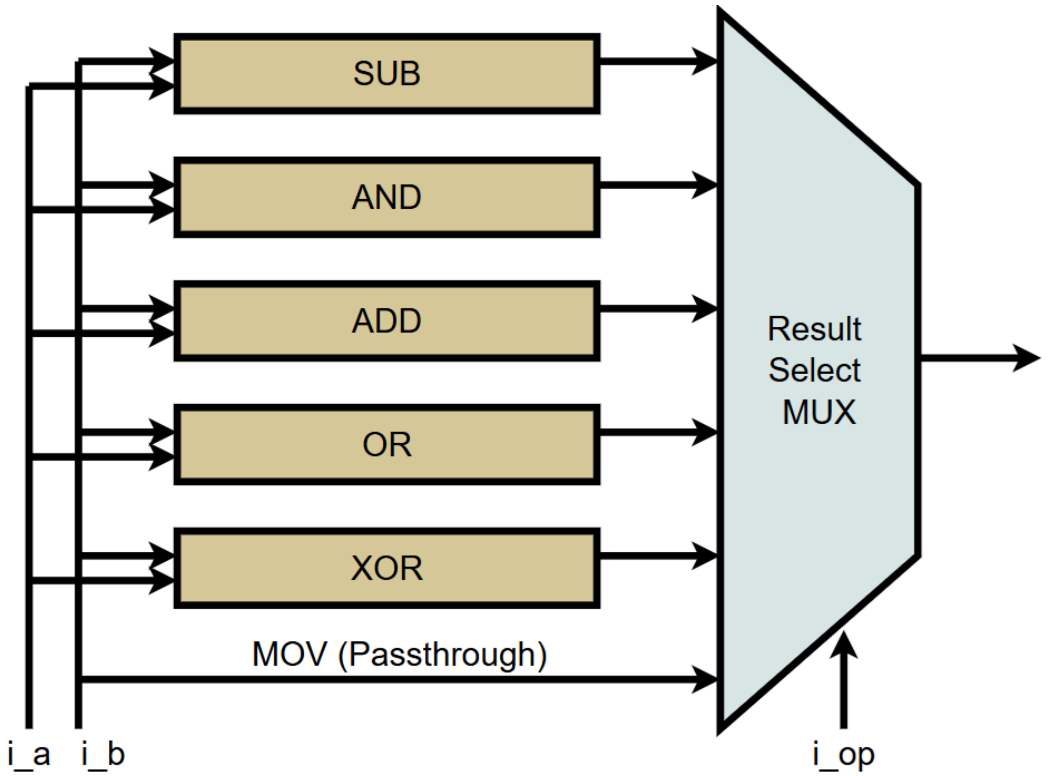
- How Registers Work:
  - When the CPU executes an instruction, it fetches the instruction from memory and stores it in the Instruction Register (IR).
  - The **Program Counter** (PC) keeps track of the next instruction to be executed.
  - Data required for the operation is loaded into registers like the Accumulator (ACC) or General-Purpose Registers.
  - After processing, the result is stored back in a register or memory.



Basic Instruction Cycle

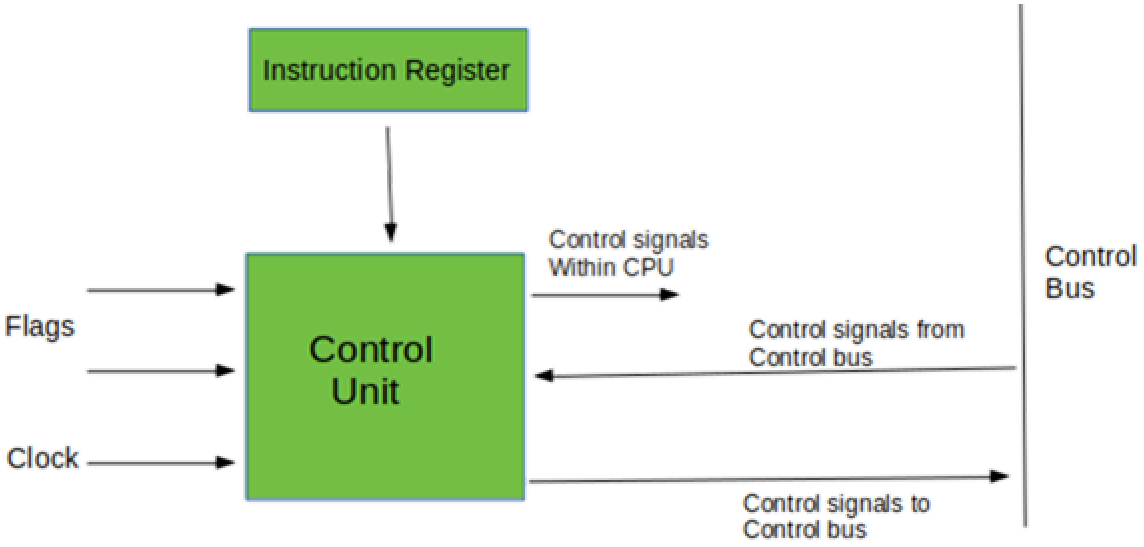
Central Processing Unit (CPU)

- **Arithmetic logic unit (ALU):** The ALU provides the circuitry needed to perform the arithmetic, logical and shift operations demanded of the instruction set.
- It performs essential computations such as addition, subtraction, multiplication, and division, as well as logical operations like AND, OR, XOR, and NOT.
- Modern processors may have multiple ALUs to enhance performance by enabling parallel processing of instructions.



Central Processing Unit (CPU)

- **Control unit (CU)**:
  - Its primary function is to direct the operation of the processor.
  - The control unit is the entity responsible for fetching the instruction to be executed from the main memory and decoding and then executing.
  - The CU interprets instructions from the computer's memory and converts them into a sequence of control signals.

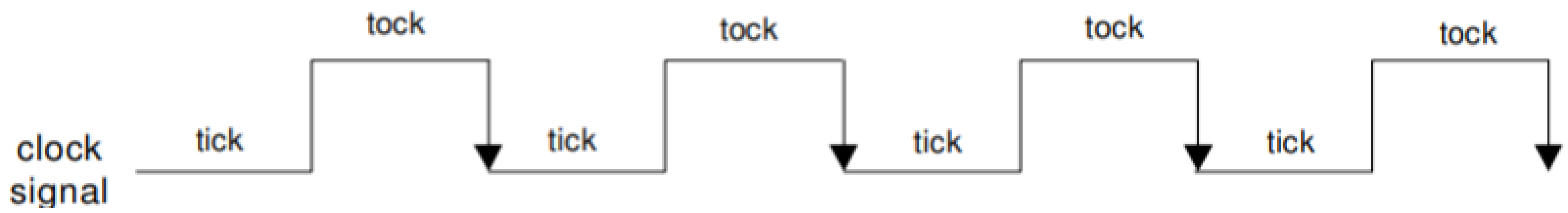


Block Diagram of the Control Unit

Clock cycle

Clock and Clock cycle

- The clock in a CPU is a critical component that synchronizes the operations of the processor and other parts of the computer system.
- It generates a series of regular electrical pulses, known as the clock signal.
- The clock ensures that all components of the CPU work in harmony by providing a timing reference for the fetch-decode-execute cycle and other operations.

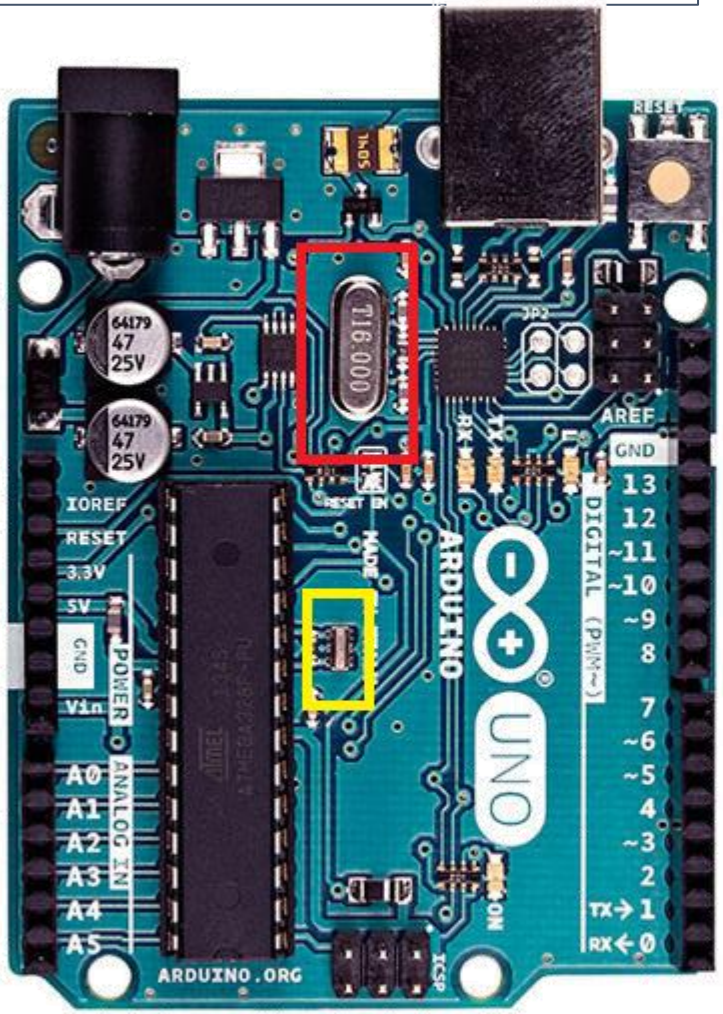


Clock cycle

Clock and Clock cycle

- The clock signal is generated by a clock generator, which is typically a quartz crystal oscillator.

- This oscillator produces a stable and precise frequency, ensuring that the CPU operates reliably.



Clock cycle

Clock and Clock cycle

- The clock refers to a microchip that regulates the timing and speed of all computer functions.

- A clock cycle is defined as the time interval between rising edges of a repetitive clock signal.

- A computer processor or CPU (Central Processing Unit) speed is determined by the clock cycle

Clock cycle

Clock and Clock cycle

- The clock speed is measured in Hz, often either MHz (megahertz) or GHz (gigahertz).
- For example, a 4 GHz processor performs 4,000,000,000 clock cycles per second.
- $cycle\ time = \dfrac{1}{clock\ cycle} = \dfrac{1}{4GHz} =$ 0.00000000025 = 0.25ns/cycle

Example 1

A processor has a clock frequency of 2 GHz. Determine the duration of one clock cycle and find out how many cycles it completes in 5 milliseconds.

Solution

a 2 GHz processor performs 2,000,000,000 clock cycles per second.

Clock Cycle Duration

- T($cycle\ time$) = $\frac{1}{f} = \frac{1}{2GHz}$ = 0.0000000005 = 0.5×10^{-9} =0.5 ns/cycle

Number of Cycles in 5 ms:

- = 2,000,000,000 x 5 x 10^{-3} = $\frac{5x10^{-3}}{0.5\times10^{-9}}$ = 10 x 10^{6} cycle

Example 2

A processor executes an instruction that takes 2 ns to complete. If the clock cycle time is 0.5 ns, how many clock cycles does the instruction take?

Solution

- Clock Cycles = $\frac{Instruction\ Execution\ Time}{Clock\ Cycle\ Time} = \frac{2\ ns}{0.5\ ns} = 4$ cycles

Example 3

A program consists of 1,000 instructions. Each instruction takes 4 clock cycles to execute. If the processor operates at a clock frequency of 1 GHz, what is the total execution time for the program?

Solution

a 1 GHz processor performs 1,000,000,000 clock cycles per second.

Clock Cycle Duration

- T($cycle\ time$) = $\frac{1}{f} = \frac{1}{1GHz} = 1\ ns$

Example 3

The total number of clock cycles

Total Clock Cycles=Number of Instructions × Clock Cycles per Instruction

=1,000×4

=4,000 cycles

the total execution time

Total Execution Time=Total Clock Cycles × T

= 4,000 × 1 ns

= 4,000 ns

= 4 microseconds (µs)

Example 4

Processor A operates at 2 GHz and takes 3 clock cycles per instruction. **Processor B** operates at 3 GHz and takes 2 clock cycles per instruction. Which processor is faster, and by how much?

Solution

the clock cycle time for each processor

- $T_A = \frac{1}{f} = \frac{1}{2GHz} = 0.5\,ns$
- $T_B = \frac{1}{f} = \frac{1}{3GHz} = 0.333\,ns$

Example 4

Solution

calculate the time per instruction for each processor:

- Processor A: Time per Instruction=3×0.5 ns=1.5 ns
- Processor B: Time per Instruction=2×0.333 ns=0.666 ns

Processor B is faster, and the speedup is:

Speedup $= \frac{1.5\ ns}{0.66\ ns} = 2.25$ times

Example 5

A program consists of 1 million instructions. The processor executes instructions with an average CPI (Clock Cycles Per Instruction) of 2. The clock frequency is 2.5 GHz. Calculate the total execution time.

Solution

The execution time is given by the formula:

$$\text{CPU Time} = \frac{Number\ of\ Instructions \times CPI}{clock\ frequency} = \frac{1x\ 10^{6}\ x\ 2}{2.5\ GHz} = 0.8\ ms$$

the execution time is 0.8 milliseconds (ms).

Example 6

A program takes 5 ms to execute on a processor with a 2 GHz clock and executes 10 million instructions. Find the Clock Cycles Per Instruction (CPI).

Solution

The execution time is given by the formula:

Clock Cycles Per Instruction CPI = $\frac{clock\ frequency \times CPU\ time}{Number\ of\ Instructions}$

$$= \frac{2x\ 10^{9}\, x\ 5\ x\ 10^{-3}}{10\ x\ 106} = 1$$

Example 7

A processor runs at 2 GHz and executes a program in 10 seconds. If the processor is upgraded to 3 GHz, how long will the program take to execute (assuming the same CPI and instruction count)?

Solution

Execution time is inversely proportional to clock speed

New Time = Old Time x $\frac{Old\ Frequency}{New\ Frequency}$

$$= 10\ x\ \frac{2x\ 10^{9}}{3x\ 10^{9}} = 6.66\ sec$$

MICROPROCESSOR VERSUS MICROCONTROLLER

Processors

- Up to now, we have used the general term " processor " for the entire assortment of processing units containing some kind of CPU.

- A processor is a broad term that refers to any device or unit capable of processing data.

- However, under the processor class, there are two distinct subclasses, microprocessors and microcontrollers.

- This can include central processing units (CPUs), graphics processing units (GPUs), digital signal processors (DSPs),

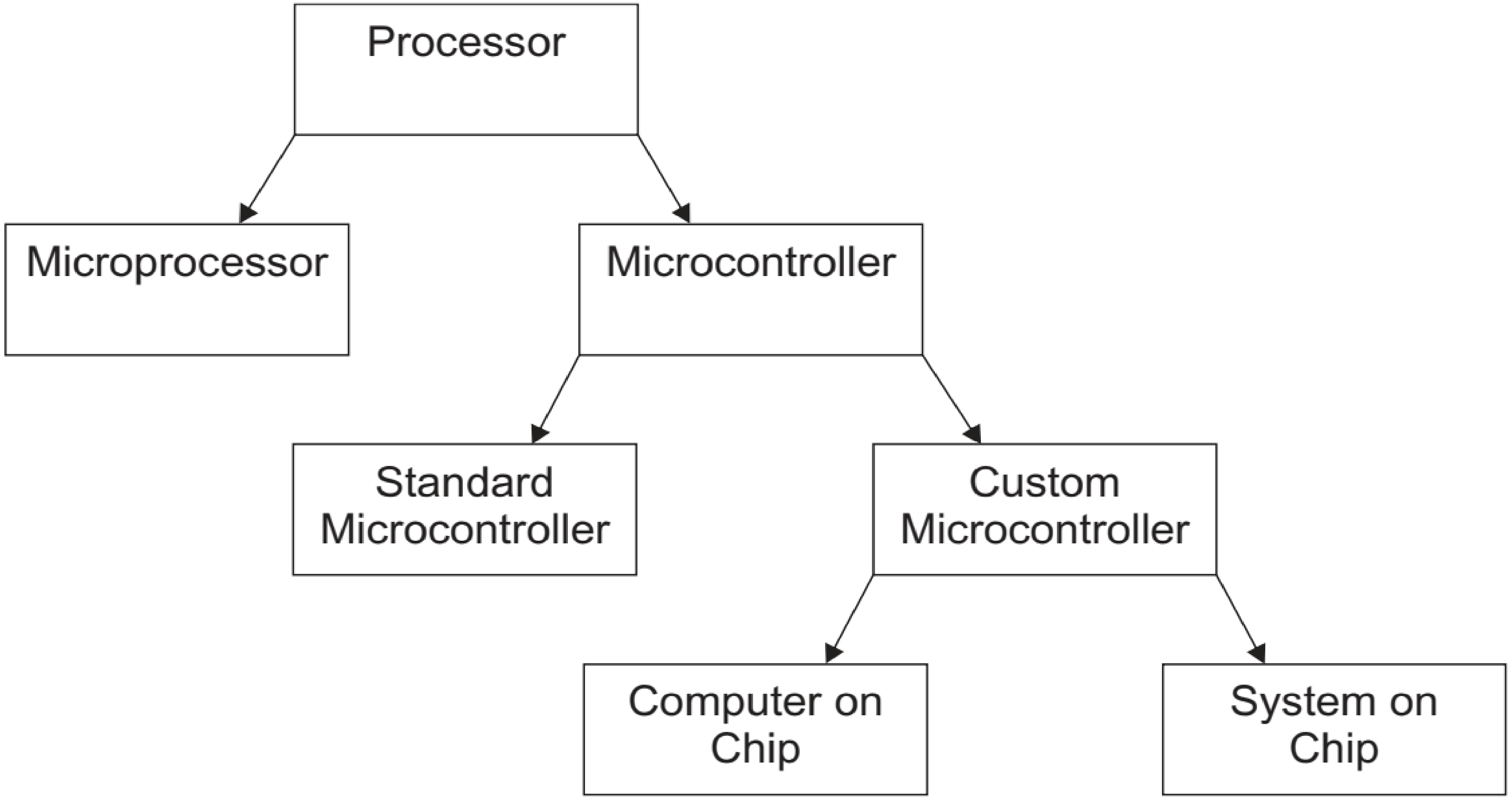
Processors

- **Digital signal processors (DSPs)**: DSPs are specialized for high-speed numeric calculations and are often used for demanding tasks like audio processing, telecommunications and image processing

  - **Graphics processing units (GPUs)**: GPU processors are specially designed for the demanding task of rendering digital video and graphics requiring high-powered performance and parallel processing.

  - GPU rocessors are also commonly used in cryptocurrency mining and are known for high power consumption.

Processors


Processor
Microprocessor
Microcontroller
Standard Microcontroller
Custom Microcontroller
Computer on Chip
System on Chip

Microprocessors

- A microprocessor is a specific type of processor that integrates the functions of a CPU onto a single integrated circuit (IC).
- Microprocessors are widely used in personal computers, embedded systems, and other electronic devices.
- first embedded systems were designed that were based on microprocessors and a set of external memory and I/O devices.

Microcontrollers (standard)

- A microcontroller is an integrated circuit containing a CPU, as well as an interconnected set of memory devices, peripheral interface units, timers/counters, etc.
- Hence, the microcontroller can take direct input from devices and sensors and directly control external actuators.
- A modern microcontroller could contain the following set of PIUs and memory devices:
  - SRAM, EEPROM or Flash
  - ADC
  - Direct - memory - access controller
  - Parallel inputs and outputs
  - Serial interface
  - Timers and counters
  - Pulse - width modulators
  - Watchdog timer

Microcontrollers (standard)

- Essentially, a microcontroller is a small computer on a single chip containing:
  - **Central processing unit** (CPU): A processor core (or cores), Colloquially referred to as the computer's "brain," the CPU is responsible for executing instructions and controlling operations.
  - **Memory**: Microcontrollers contain both volatile memory (RAM), which stores temporary data that may be lost if the system loses power, and non-volatile flash memory (ROM) for storing the microcontroller's programming code.
  - **Peripherals**: Depending on the intended application, a microcontroller may contain various peripheral components, such as I/O interfaces, timers, counters, analog-to-digital converters (ADCs) and communication protocols (UART, SPI, I2C).

Microcontrollers (standard)

- **Microcontroller types**
  - **8-bit microcontrollers:** The most basic type of microcontroller features limited processing and memory and typically used in small appliances, such as toys and remote controls.
  - **16-bit microcontrollers:** 16-bit microcontrollers are used for more complex applications, including medical devices, automotive systems and industrial control systems.
  - **32-bit microcontrollers:** The most powerful and feature-rich type of microcontrollers, these are used for demanding applications, such as gaming consoles, entertainment devices and high-end industrial automation.

Microcontrollers (standard)

- **<u>Microcontroller types</u>**
  - **Reduced instruction set computer** (RISC) microcontrollers: RISC microcontrollers incorporate a design architecture that simplifies and improves operations by executing fewer compute instructions faster than other methodologies, such as the complex instruction set computer (CISC) architecture.
  - **<u>ARM microcontrollers</u>**: Formerly an acronym for Advanced RISC Machines, these types of microcontrollers incorporate the ARM architecture, including the modern Arm Cortex subset, that bolster performance and reliability.
  - Arm microcontrollers are widely used in mobile devices, automotive systems and industrial control systems.

Microcontrollers (standard)

- **Microcontroller types**
  - **PIC Microcontrollers**: Developed by Microchip Technology, the PIC Microcontroller is the world's smallest microcontroller, and it is found frequently in robotics, home and industrial automation and renewable energy systems.
  - **FPGA-based microcontrollers**: Commonly used in applications necessitating digital signal processing, video processing and high-speed networking, these microcontrollers use customizable chips called **field-programmable gate arrays** (FPGAs), which can be configured and reconfigured on the hardware level to create unique hardware solutions for demanding processing requirements.

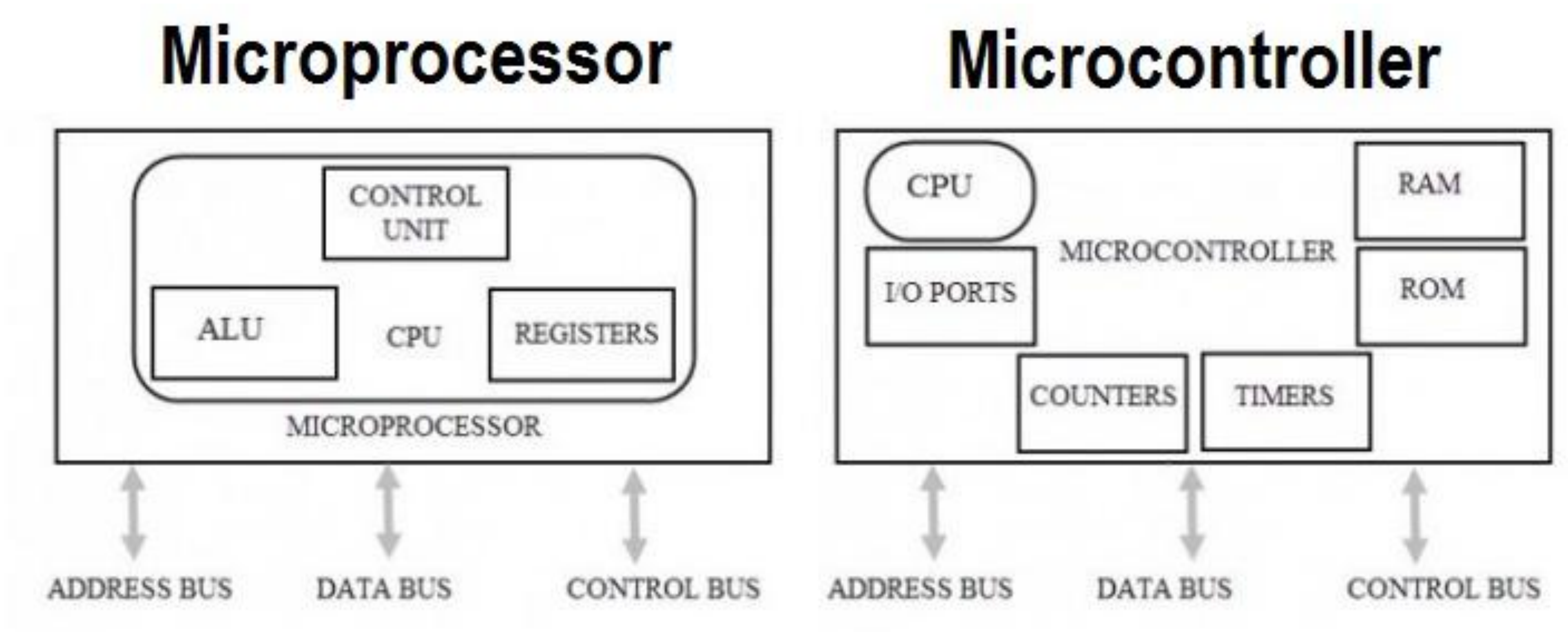
Custom Microcontrollers

- A custom microcontroller, on the other hand, is specifically designed and tailored for a particular application.

- These microcontrollers are either modified versions of existing microcontrollers or entirely new designs created to meet specific requirements such as power efficiency, specialized input/output interfaces, or enhanced processing speed.

- Custom microcontrollers are commonly used in proprietary systems where performance optimization and hardware-software integration are critical

Microcontrollers vs. Microprocessors



Microcontrollers vs. Microprocessors

Feature	Microcontroller	Microprocessor
Purpose	Designed for specific, embedded applications.	Designed for general-purpose computing tasks.
Components	Includes CPU, RAM, ROM, I/O ports, timers, ADC, etc., on a single chip.	Only includes the CPU; external components like RAM, ROM, and I/O are required.
Cost	Lower cost due to integrated components.	Higher cost due to the need for external components.
Power Consumption	Low power consumption, ideal for battery-operated devices.	Higher power consumption, suitable for power-rich environments.

Microcontrollers vs. Microprocessors

- **<u>Top 8-bit Microcontrollers (MCU) Manufacturers in the World</u>**

MICROCHIP

life.augmented

SILICON LABS

infineon

NXP

TEXAS INSTRUMENTS

Thank You