Computer Architecture

Lecture-02

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Reference

- "Computer Organization and Architecture" by William Stallings; 8th Edition.
  - Any later edition is fine.
- https://www.javatpoint.com/general-system-architecture
- https://www.tutorialspoint.com/computer_fundamentals/computer_fifth_generation.htm

Evolution of Computers

- First Generation: **Vacuum Tubes**
  - ENIAC (Electronic Numerical Integrator And Computer).
  - Designed and constructed at the University of Pennsylvania.
  - World's first general purpose electronic digital computer.
- Second Generation: **Transistors**
  - The first major change in the electronic computer came with the replacement of the vacuum tube by the transistor.
    - The transistor was invented at Bell Labs in 1947
  - The transistor is smaller & cheaper, and generates less heat than a vacuum tube but can be used in the same way as a vacuum tube to construct computers.
  - Unlike the vacuum tube, which requires wires, metal plates, a glass capsule, and a vacuum, the transistor is a solid-state device, made from silicon.

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- Third & Forth Generation: **Integrated Circuits (IC) & VLSI.**
  - In 1958 came the achievement that revolutionized electronics and started the era of microelectronics: the invention of the integrated circuit.
  - Microelectronics means, literally, “small electronics”.
  - The basic elements of a digital computer: only two fundamental types of components are required.
    - Gates and memory cells.
  - A gate is a device that implements a simple Boolean or logical function, such as IF A AND B ARE TRUE THEN C IS TRUE (AND gate).
  - Such devices are called gates because they control data flow in much the same way that canal gates do.
  - The memory cell is a device that can store one bit of data; that is, the device can be in one of two stable states at any time.
  - By interconnecting large numbers of these fundamental devices, we can construct a computer.

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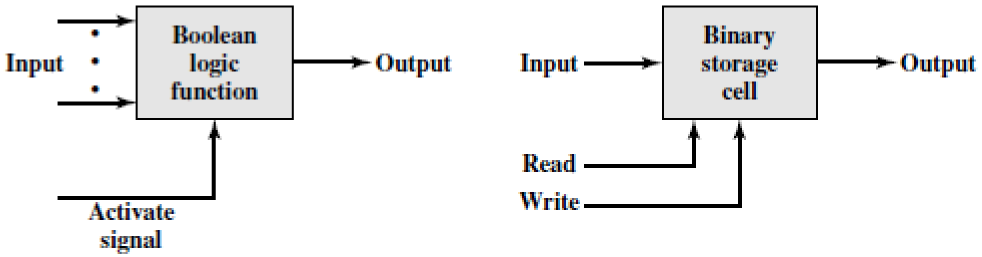
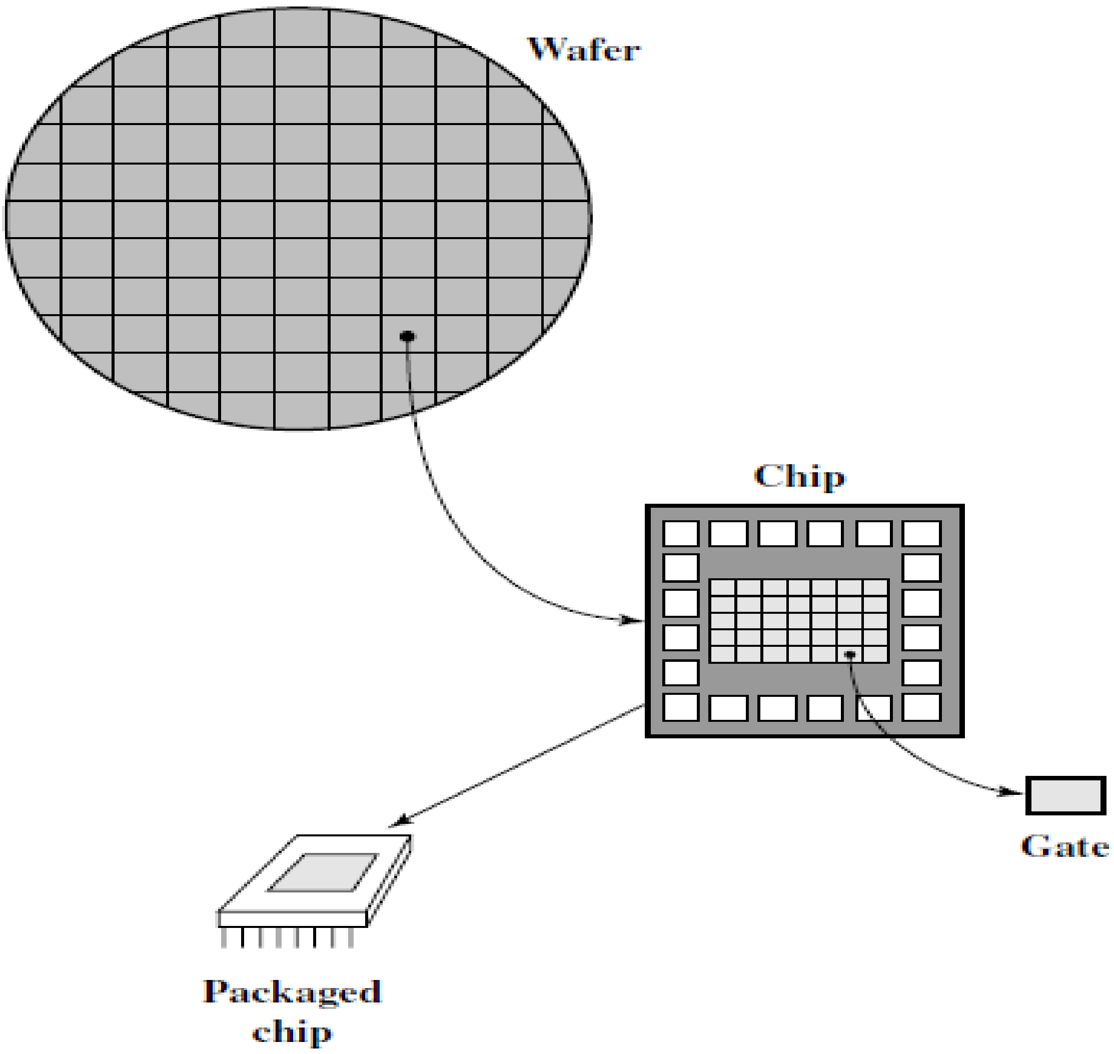
- Four basic functions could be related to these two components as follows:
  - Data storage: Provided by memory cells.
  - Data processing: Provided by gates.
  - Data movement: The paths among components are used to move data from memory through gates to memory.
  - Control: The paths among components can carry control signals.
  - For example, a gate will have one or two data inputs plus a control signal input that activates the gate.
  - When the control signal is ON, the gate performs its function on the data inputs and produces a data output.
  - Similarly, the memory cell will store the bit that is on its input lead when the WRITE control signal is ON and will place the bit that is in the cell on its output lead when the READ control signal is ON.



Relationship Among Wafer, Chip, and Gate



Fabrication of Integrated Circuits

- A thin wafer of silicon is divided into a matrix of small areas, each a few millimeters square.
- The identical circuit pattern is fabricated in each area, and the wafer is broken up into chips.
- Each chip consists of many gates and/or memory cells plus a number of input and output attachment points.
- This chip is then packaged in housing that protects it and provides pins for attachment to devices beyond the chip.
- A number of these packages can then be interconnected on a printed circuit board to produce larger and more complex circuits.

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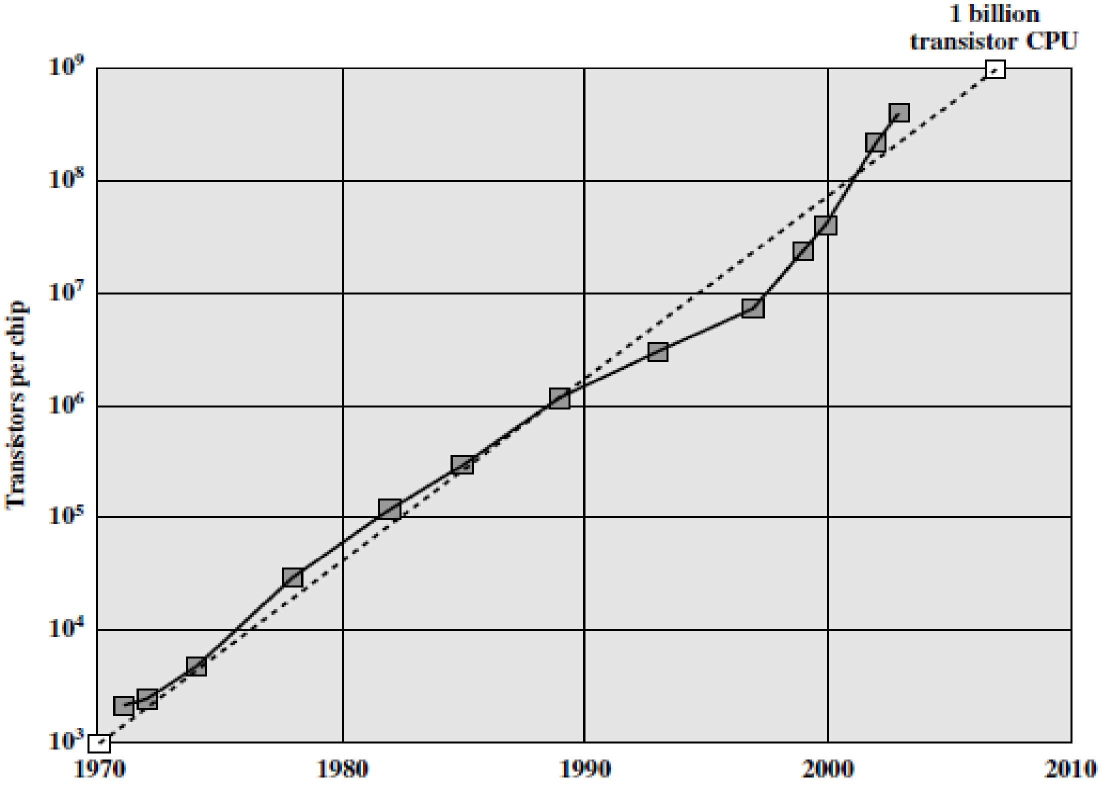
- Initially, only a few gates or memory cells could be reliably manufactured and packaged together.
- These early integrated circuits are referred to as small-scale integration (SSI).
- As time went on, it became possible to pack more and more components on the same chip.
- And so comes the terms- MSI, LSI, VLSI and ULSI.

Fifth Generation

- The period of fifth generation is 1980-till date.
- In the fifth generation, VLSI technology became ULSI (Ultra Large Scale Integration) technology, resulting in the production of microprocessor chips having ten million electronic components.
- This generation is based on parallel processing hardware and AI (Artificial Intelligence) software.
- The main features of fifth generation are −
  - ULSI technology
  - Development of artificial intelligence
  - Development of Natural language processing
  - Advancement in Parallel Processing
  - Advancement in Superconductor technology
  - More user-friendly interfaces with multimedia features
  - Availability of very powerful and compact computers at cheaper rates

Moore’s law

- Moore's law is the observation that the number of transistors in a dense integrated circuit doubles about every two years.
- Moore's law is an observation and projection of a historical trend.
- Rather than a law of physics, it is an empirical relationship linked to gains from experience in production.



Moore’s law

- The consequences of Moore’s law are profound:
- The cost of a chip has remained virtually unchanged during this period of rapid growth in density.
  - This means that the cost of computer logic and memory circuitry has fallen at a dramatic rate.
- Because logic and memory elements are placed closer together on more densely packed chips, the electrical path length is shortened, increasing operating speed.
- The computer becomes smaller, making it more convenient to place in a variety of environments.
- There is a reduction in power and cooling requirements.
- The interconnections on the integrated circuit are much more reliable than solder connections.
  - With more circuitry on each chip, there are fewer inter-chip connections.

Comparison – Among Generations

Generation	Approximate Dates	Technology	Typical Speed (operations per second)
1	1946–1957	Vacuum tube	40,000
2	1958–1964	Transistor	200,000
3	1965–1971	Small and medium scale integration	1,000,000
4	1972–1977	Large scale integration	10,000,000
5	1978–1991	Very large scale integration	100,000,000
6	1991–	Ultra large scale integration	1,000,000,000

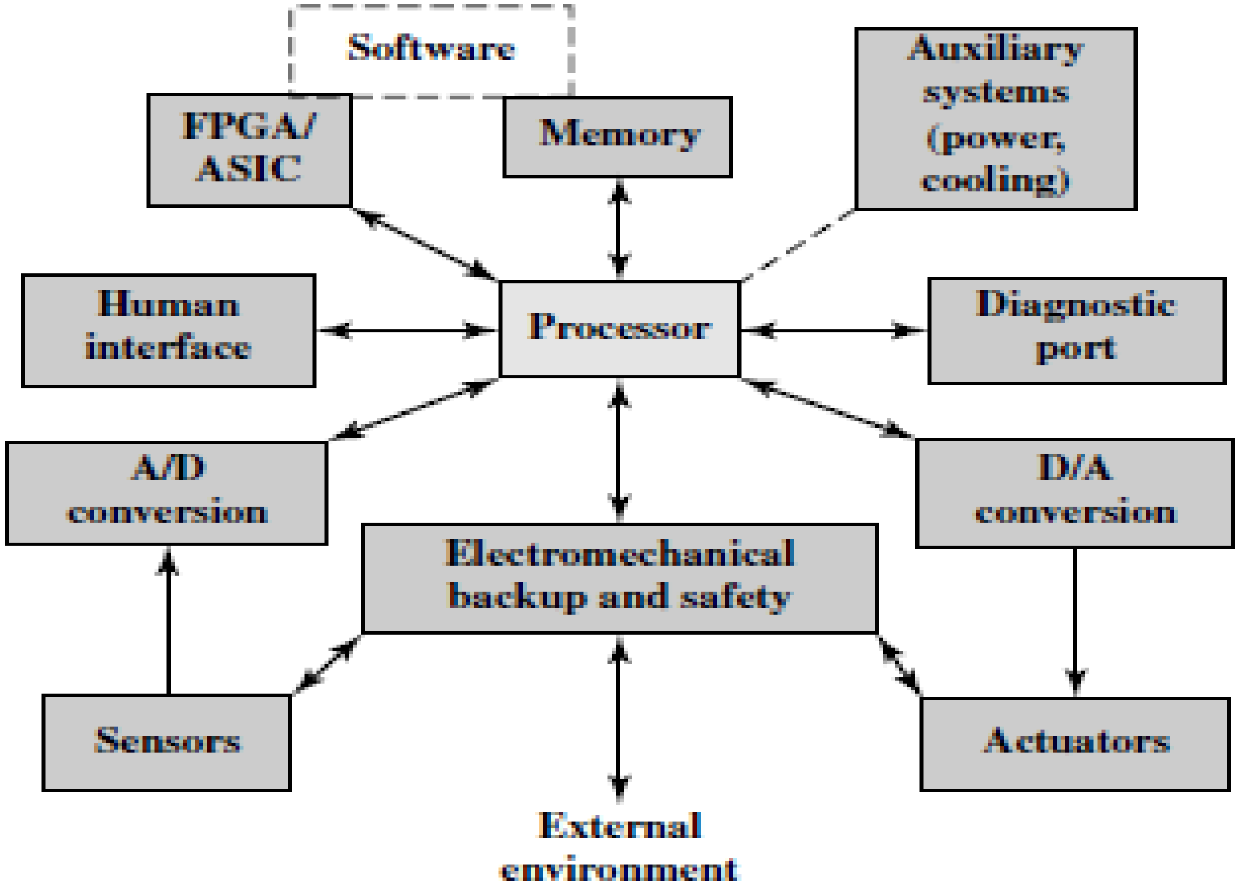
EMBEDDED SYSTEMS

- The term embedded system refers to the use of electronics and software within a product, as opposed to a general-purpose computer, such as a laptop or desktop system.
- The following is a good general definition:
  - A combination of computer hardware and software, and perhaps additional mechanical or other parts, designed to perform a dedicated function.
- In many cases, embedded systems are part of a larger system or product.
- Example: ATM system.

Embedded Systems & Their Markets

Market	Embedded Device
Automotive	Ignition system Engine control Brake system
Consumer electronics	Digital and analog televisions Set-top boxes (DVDs, VCRs, Cable boxes) Personal digital assistants (PDAs) Kitchen appliances (refrigerators, toasters, microwave ovens) Automobiles Toys/games Telephones/cell phones/pagers Cameras Global positioning systems
Industrial control	Robotics and controls systems for manufacturing Sensors
Medical	Infusion pumps Dialysis machines Prosthetic devices Cardiac monitors
Office automation	Fax machine Photocopier Printers Monitors Scanners

Organization of an Embedded System



General System Architecture

- In Computer Architecture, the General System Architecture is divided into two major classification units.
  - Store Program Control Concept.
  - Flynn's Classification of Computers.

Store Program Control Concept

- The term **Stored Program Control Concept** refers to the storage of instructions in computer memory to enable it to perform a variety of tasks in sequence or intermittently.
- The idea was introduced in the late 1940s by John von Neumann who proposed that a program be electronically stored in the binary-number format in a memory device so that instructions could be modified by the computer as determined by intermediate computational results.
- **ENIAC (Electronic Numerical Integrator and Computer)** was the first computing system designed in the early 1940s. It was based on Stored Program Concept in which machine use memory for processing data.

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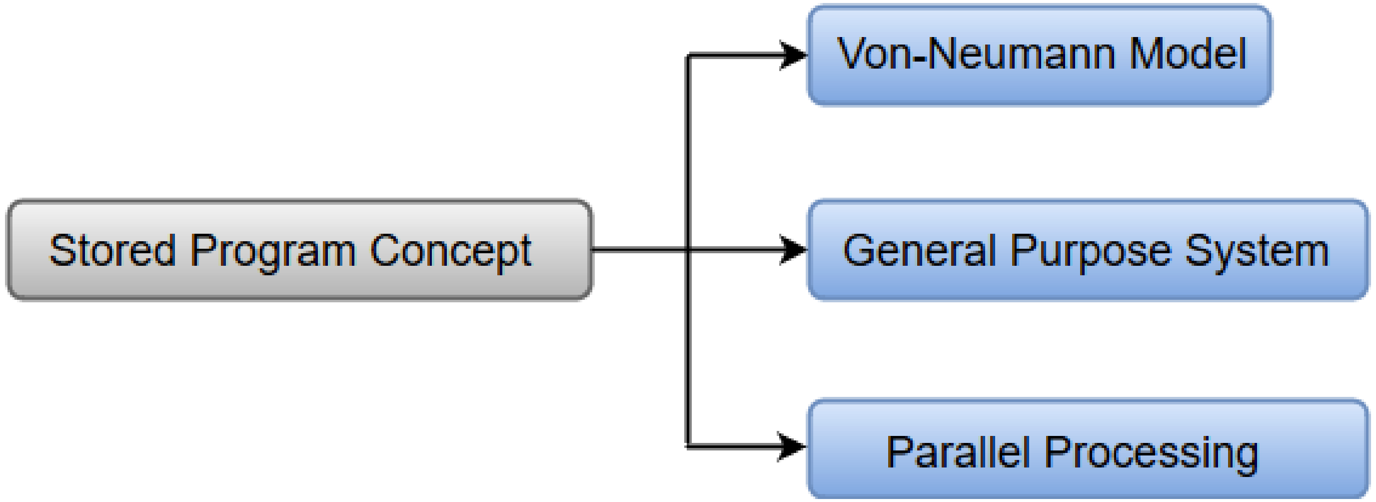
- Stored Program Concept can be further classified in three basic ways:



Von-Neumann Model

- Von-Neumann proposed his computer architecture design in 1945 which was later known as Von-Neumann Architecture.
- It consisted of a Control Unit, Arithmetic & Logical Memory Unit (ALU), Registers and Inputs/Outputs.
- Von Neumann architecture is based on the stored-program computer concept, where instruction data and program data are stored in the same memory.
- This design is still used in most computers produced today.
- A Von Neumann-based computer:
  - Uses a single processor.
  - Uses one memory for both instructions and data.
  - Executes programs following the fetch-decode-execute cycle.

Components of Von-Neumann Model

- Three major components are:
  - Central Processing Unit
  - Buses
  - Memory Unit
- **Central Processing Unit:**
  - The part of the Computer that performs the bulk of data processing operations is called the Central Processing Unit and is referred to as the CPU.
  - The Central Processing Unit can also be defined as an electric circuit responsible for executing the instructions of a computer program.
  - The CPU performs a variety of functions dictated by the type of instructions that are incorporated in the computer.
  - The major components of CPU are Arithmetic & Logic Unit (ALU), Control Unit (CU) and a variety of registers.

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- **Buses:**
  - Buses are the means by which information is shared between the registers in a multiple-register configuration system.
  - A bus structure consists of a set of common lines, one for each bit of a register, through which binary information is transferred one at a time.
  - Control signals determine which register is selected by the bus during each particular register transfer.
  - Von-Neumann Architecture comprised of three major bus systems for data transfer: i) Address Bus, ii) Data Bus, iii) Control Bus.

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Bus	Description
Address Bus	Address Bus carries the address of data (but not the data) between the processor and the memory.
Data Bus	Data Bus carries data between the processor, the memory unit and the input/output devices.
Control Bus	Control Bus carries signals/commands from the CPU.

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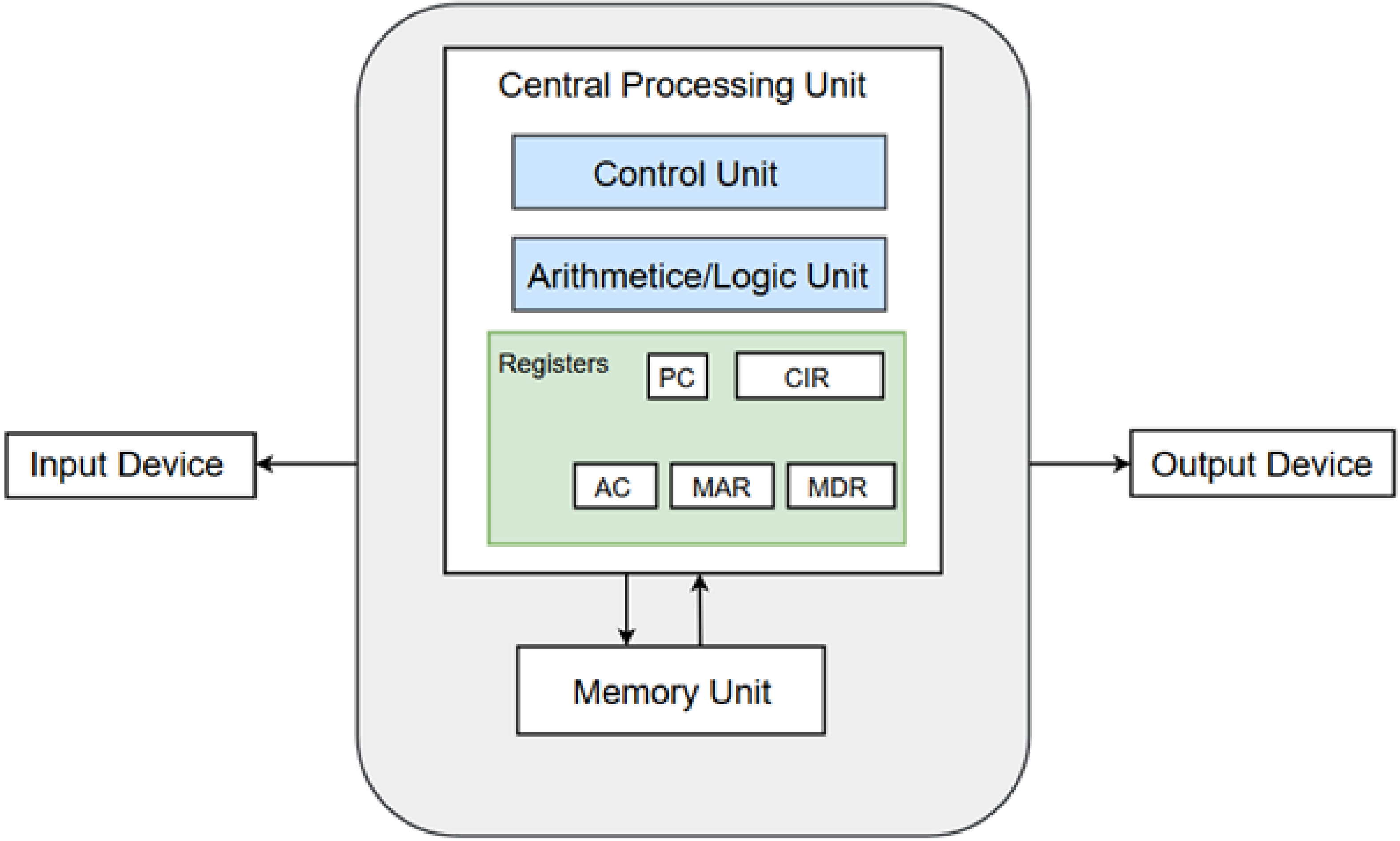
- **Memory Unit**
  - A memory unit is a collection of storage cells together with associated circuits needed to transfer information in and out of the storage.
  - The memory stores binary information in groups of bits called words.
  - The internal structure of a memory unit is specified by the number of words it contains and the number of bits in each word.
  - Two major types of memories are used in computer systems:
    - RAM (Random Access Memory)
    - ROM (Read-Only Memory)

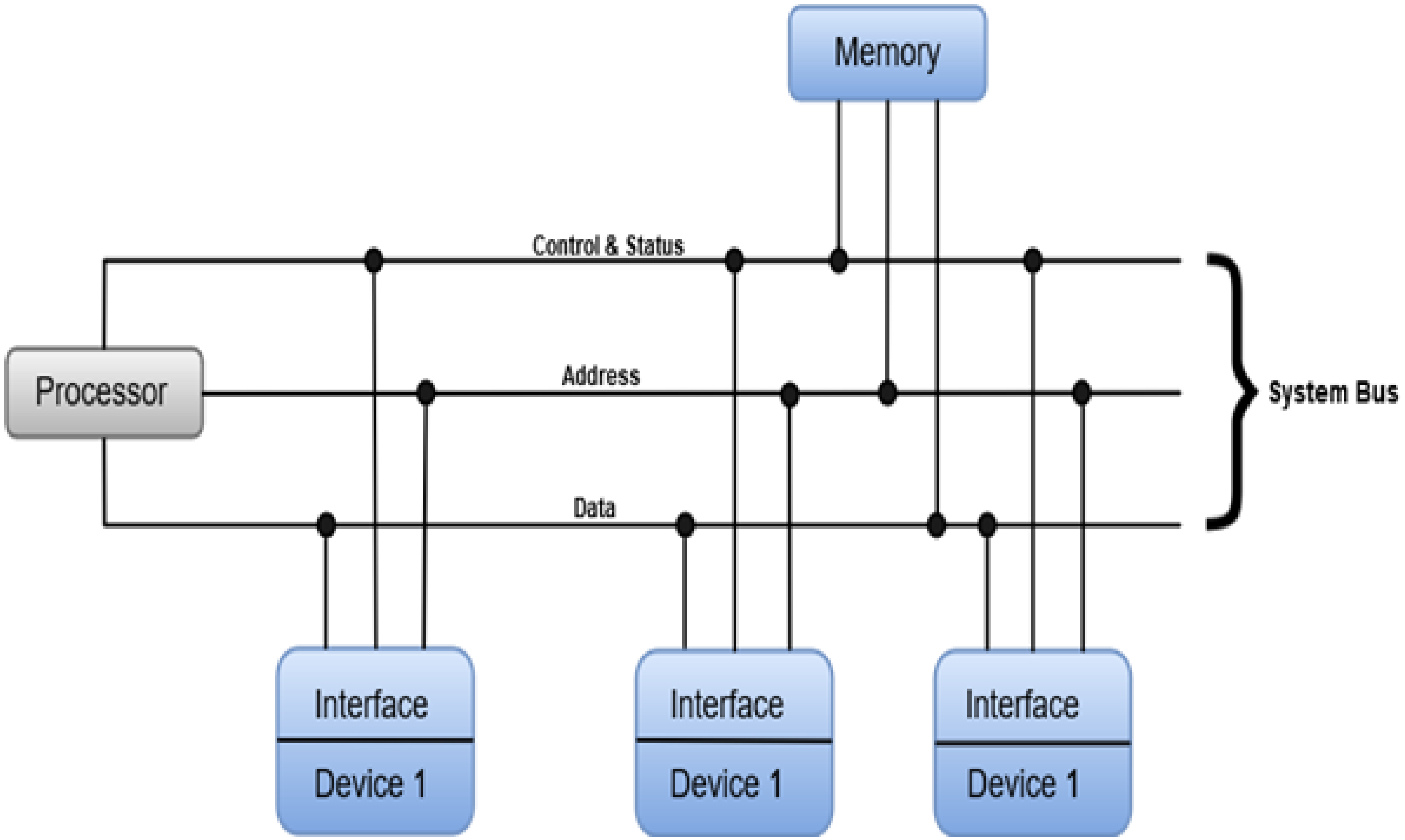
Von-Neumann Basic Structure:



General Purpose System

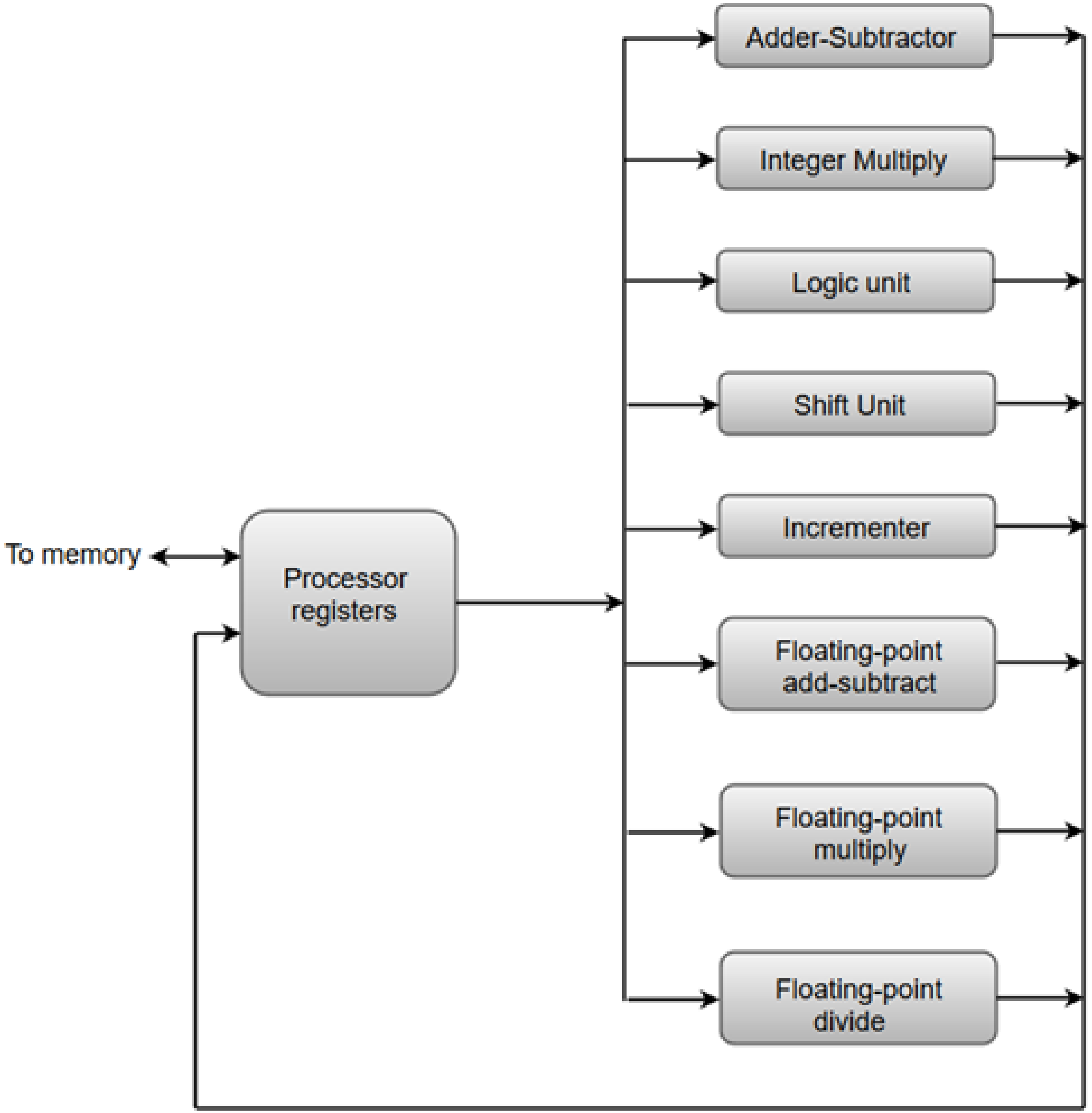
- The General Purpose Computer System is the modified version of the Von-Neumann Architecture.
- In simple words, we can say that a general purpose computer system is a modern day architectural representation of Computer System.
- The CPU consists of the ,Control Unit and various processor registers.
- The CPU, Memory Unit and I/O subsystems are interconnected by the system bus which includes data, address, and control-status lines.
- The following image shows how CPU, Memory Unit and I/O subsystems are connected through common single bus architecture.

General Purpose System



Parallel Processing

- Parallel processing can be described as a class of techniques which enables the system to achieve simultaneous data-processing tasks to increase the computational speed of a computer system.
- A parallel processing system can carry out simultaneous data-processing to achieve faster execution time.
- For instance, while an instruction is being processed in the ALU component of the CPU, the next instruction can be read from memory.
- The primary purpose of parallel processing is to enhance the computer processing capability and increase its throughput, i.e. the amount of processing that can be accomplished during a given interval of time.
- A parallel processing system can be achieved by having a multiplicity of functional units that perform identical or different operations simultaneously. The data can be distributed among various multiple functional units.
- The following diagram shows one possible way of separating the execution unit into eight functional units operating in parallel.


Adder-Subtractor
Integer Multiply
Logic unit
Shift Unit
Incrementer
Floating-point add-subtract
Floating-point multiply
Floating-point divide
To memory
Processor registers

Parallel Processing…

- The adder and integer multiplier performs the arithmetic operation with integer numbers.
- The floating-point operations are separated into three circuits operating in parallel.
- The logic, shift, and increment operations can be performed concurrently on different data. All units are independent of each other, so one number can be shifted while another number is being incremented.

Flynn's Classification of Computers

- M.J. Flynn proposed a classification for the organization of a computer system by the number of instructions and data items that are manipulated simultaneously.
- The sequence of instructions read from memory constitutes an **instruction stream**.
- The operations performed on the data in the processor constitute a **data stream**.
- Parallel processing may occur in the instruction stream, in the data stream, or both.
- Flynn's classification divides computers into four major groups that are:
- Single instruction stream, single data stream (SISD)
- Single instruction stream, multiple data stream (SIMD)
- Multiple instruction stream, single data stream (MISD)
- Multiple instruction stream, multiple data stream (MIMD)

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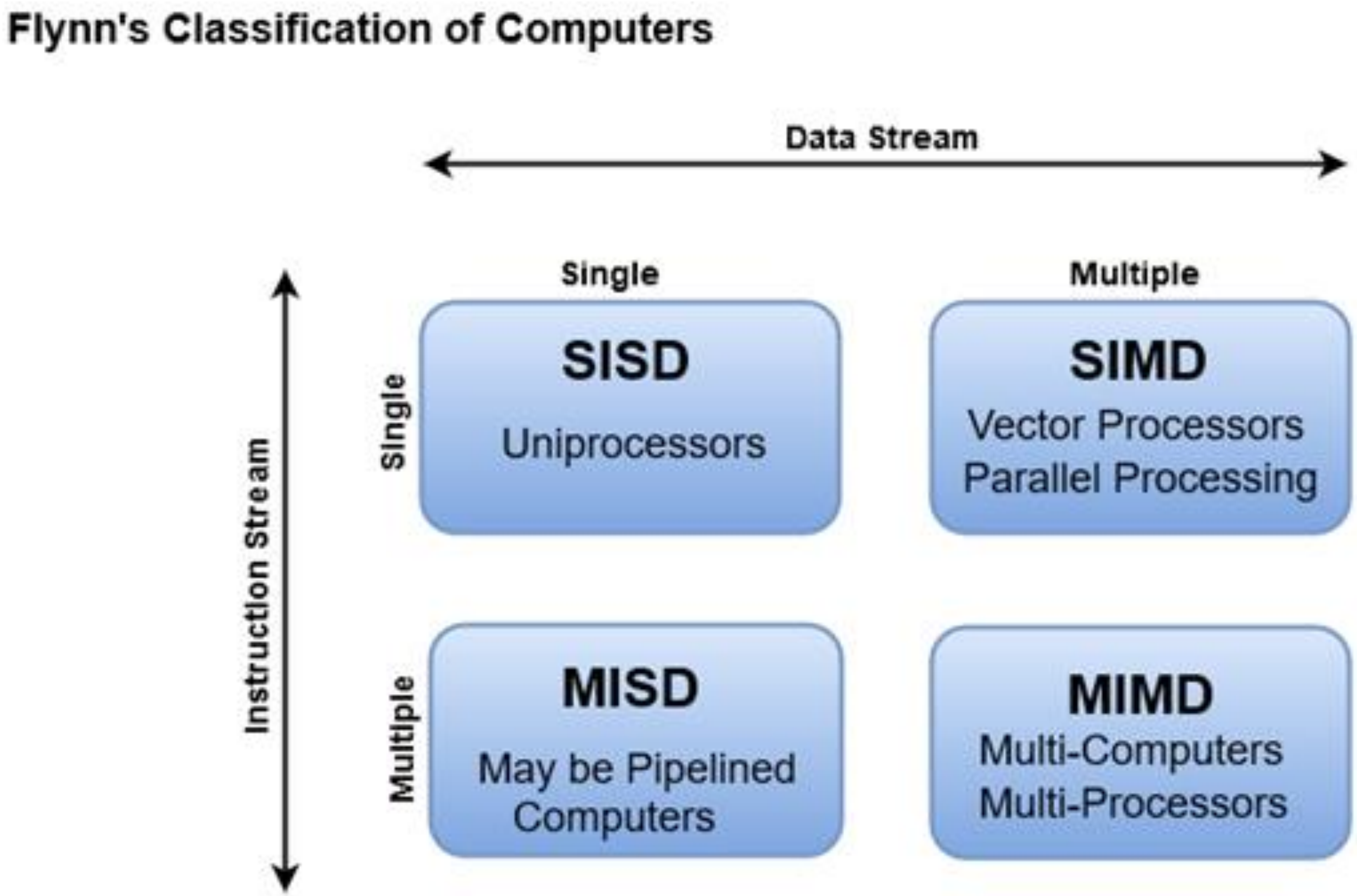
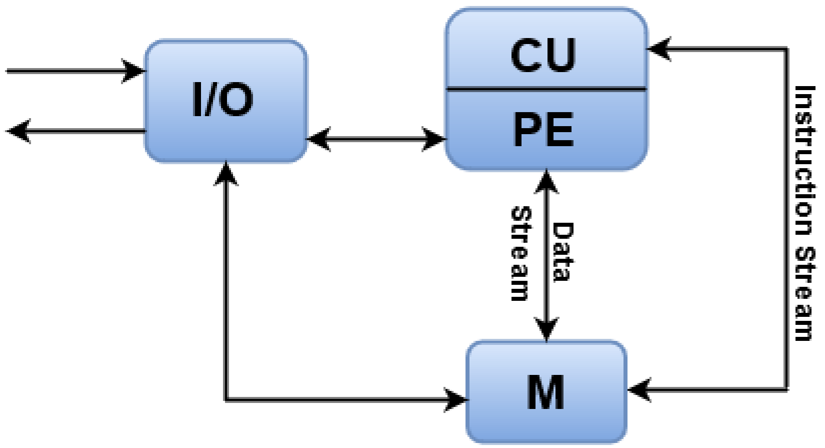


Flynn's Classification of Computers
Data Stream
Single
Multiple
Instruction Stream
Single
Multiple
SISD
Uniprocessors
SIMD
Vector Processors
Parallel Processing
MISD
May be Pipelined
Computers
MIMD
Multi-Computers
Multi-Processors

SISD

- SISD stands for 'Single Instruction and Single Data Stream'.
- It represents the organization of a single computer containing a control unit, a processor unit, and a memory unit.
- Instructions are executed sequentially, and the system may or may not have internal parallel processing capabilities.
- Most conventional computers have SISD architecture like the traditional Von-Neumann computers.
- Parallel processing, in this case, may be achieved by means of multiple functional units or by pipeline processing.

SISD:

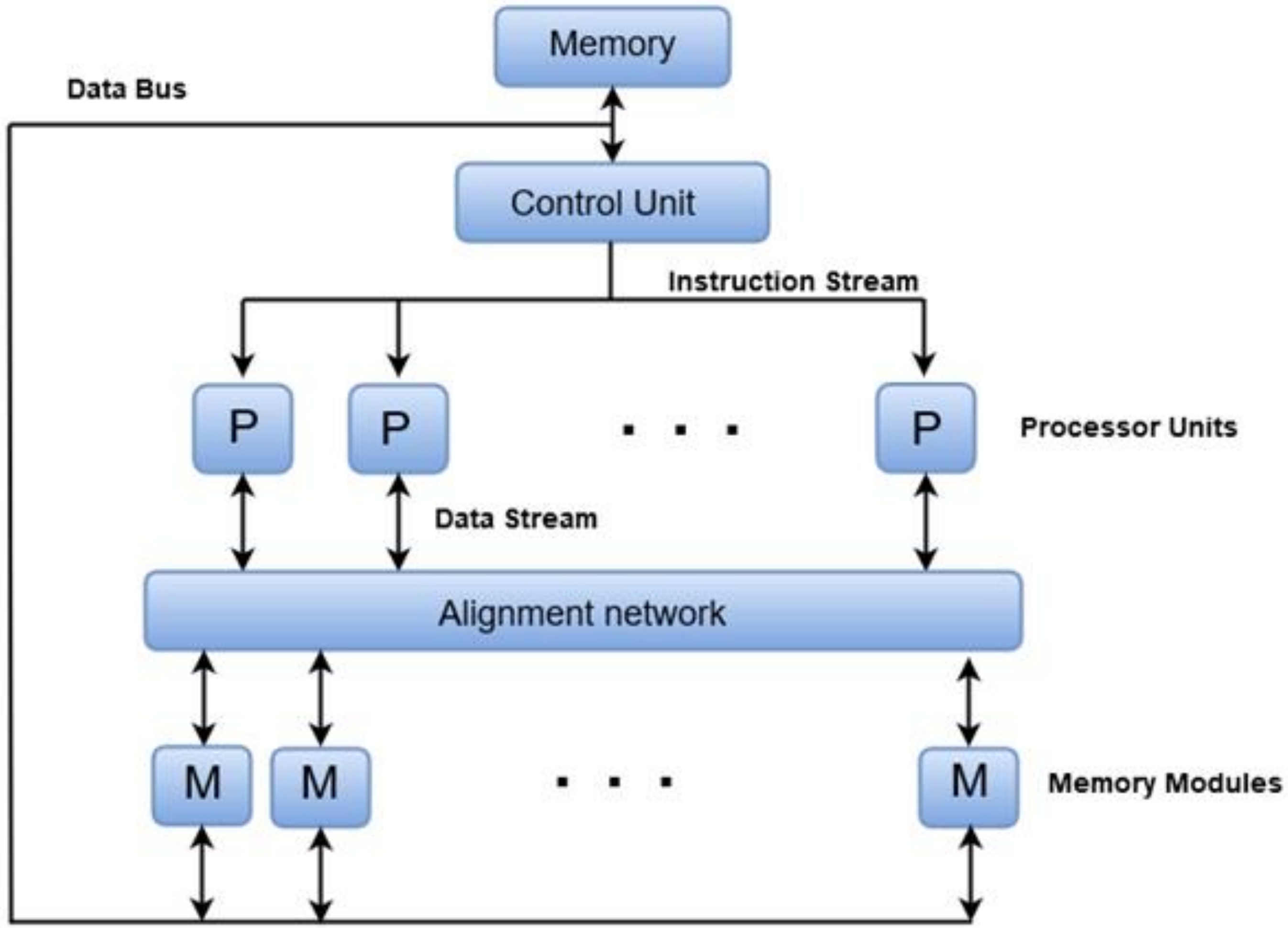


- Where, CU = Control Unit, PE = Processing Element, M = Memory
- Instructions are decoded by the Control Unit and then the Control Unit sends the instructions to the processing units for execution.
- Data Stream flows between the processors and memory bi-directionally.
- **Examples:**
- Older generation computers, minicomputers, and workstations.

SIMD

- SIMD stands for 'Single Instruction and Multiple Data Stream'.
- It represents an organization that includes many processing units under the supervision of a common control unit.
- All processors receive the same instruction from the control unit but operate on different items of data.
- The shared memory unit must contain multiple modules so that it can communicate with all the processors simultaneously.

SIMD:

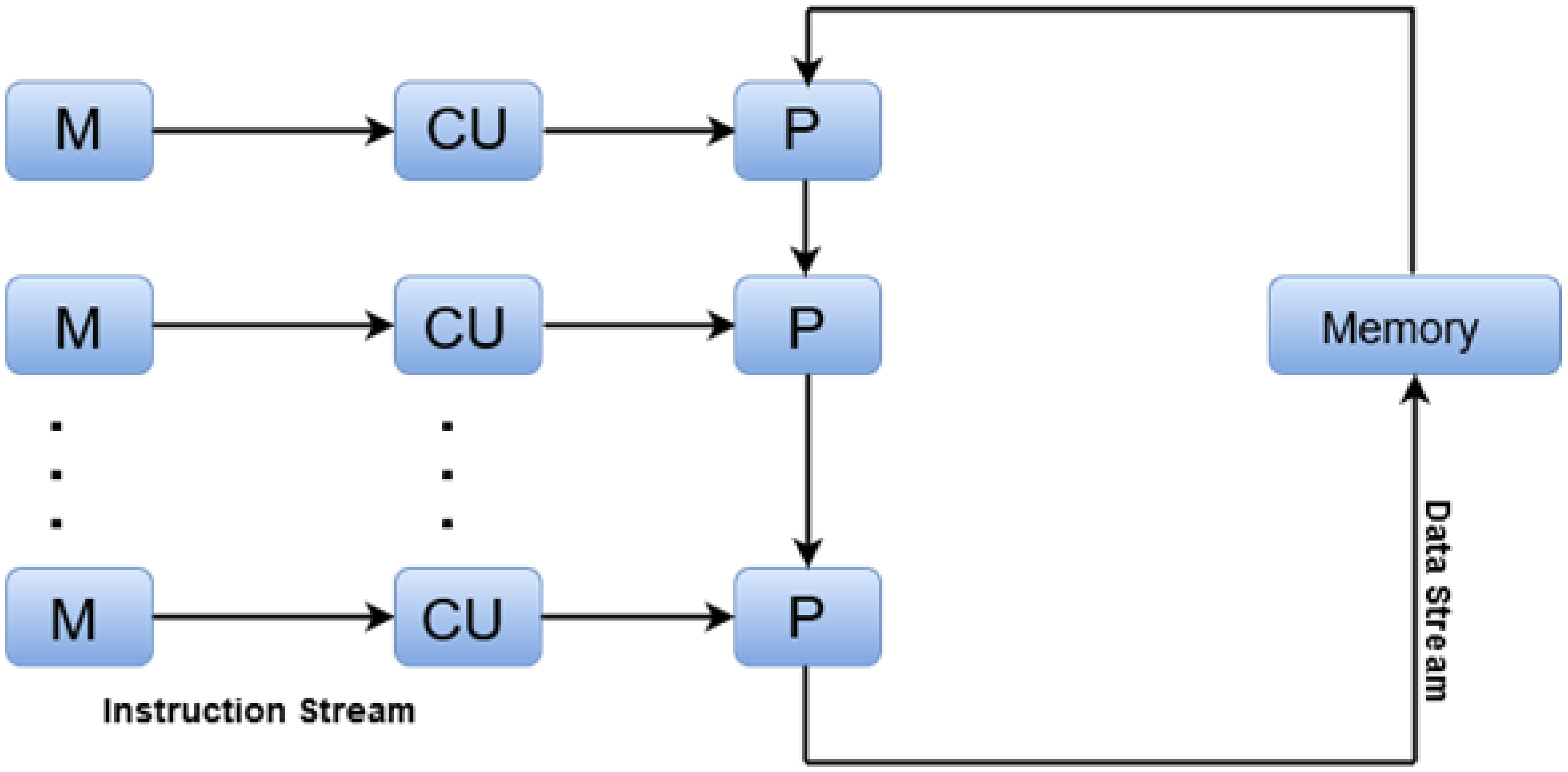


Memory
Data Bus
Control Unit
Instruction Stream
P
P
. . .
P
Processor Units
Data Stream
Alignment network
M
M
. . .
M
Memory Modules

MISD

- MISD stands for 'Multiple Instruction and Single Data stream'.
- MISD structure is only of theoretical interest since no practical system has been constructed using this organization.
- In MISD, multiple processing units operate on one single-data stream.
- Each processing unit operates on the data independently via separate instruction stream.

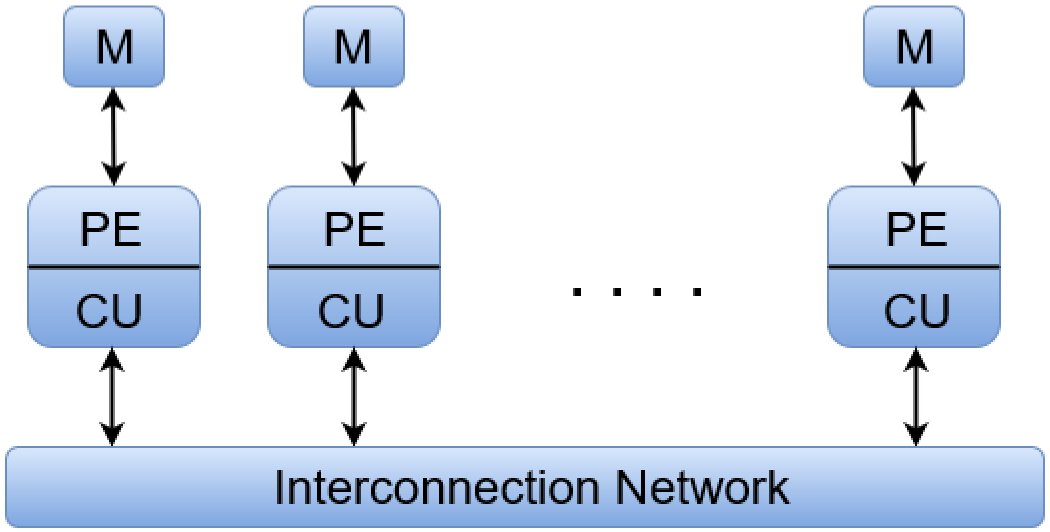
MISD:



MIMD

- MIMD stands for 'Multiple Instruction and Multiple Data Stream'.
- In this organization, all processors in a parallel computer can execute different instructions and operate on various data at the same time.
- In MIMD, each processor has a separate program and an instruction stream is generated from each program.

MIMD:



Thank You ☺