COURSE CODE: IFT 212

COURSE TITLE: COMPUTER ARCHITECTURE AND ORGANIZATION

COURSE UNIT: 2 UNITS

MODULE 1

LESSON 1.1: INTRODUCTION TO COMPUTER ARCHITECTURE

Learning Outcomes for Lesson 1.1

At the end of this lesson, you should be able to;

i) Explain the difference between computer organization and computer architecture, highlighting their distinct roles in system design.
ii) Describe the components and functions of the von Neumann architecture and its impact on modern computing.

1.1.1: Overview of Computer Organization

Computer architecture and organization are fundamental concepts that determine how a computer system operates. While both terms are closely related, they focus on different aspects of a computer's design and functionality.

Computer organization refers to the operational structure of a computer system, focusing on how hardware components interact to execute programs efficiently. It deals with the internal components of a computer and how they are interconnected.

In simple terms, computer organization answers the question: **"How does a computer function at the hardware level?"**

Key Aspects of Computer Organization:

1. **Processor (CPU) and Registers:**
    - The Central Processing Unit (CPU) is the brain of the computer, responsible for executing instructions.
    - Registers are small, high-speed storage locations within the CPU used for temporary data storage during processing.
2. **Memory Organization:**

   - Primary Memory (RAM) stores data temporarily for quick access.
   - Secondary Storage (Hard Drives, SSDs) holds data permanently.
   - Cache Memory speeds up data access by storing frequently used information close to the CPU.
3. **Input and Output (I/O) Systems:**
   - Input devices (keyboard, mouse) allow users to interact with the system.
   - Output devices (monitor, printer) display results.
   - I/O controllers manage communication between these devices and the CPU.
4. **Bus System and Data Transfer:**
   - The bus system (data bus, address bus, control bus) facilitates communication between different components.
   - The speed and width of the bus affect system performance.
5. **Control Unit and ALU (Arithmetic Logic Unit):**
   - The Control Unit (CU) directs operations, managing how data moves within the system.
   - The ALU performs mathematical and logical operations.
6. **Pipeline and Parallel Processing:**
   - Pipelining allows multiple instructions to be processed simultaneously, improving efficiency.
   - Parallel processing uses multiple processors or cores to execute tasks faster.

Difference Between Computer Architecture and Organization

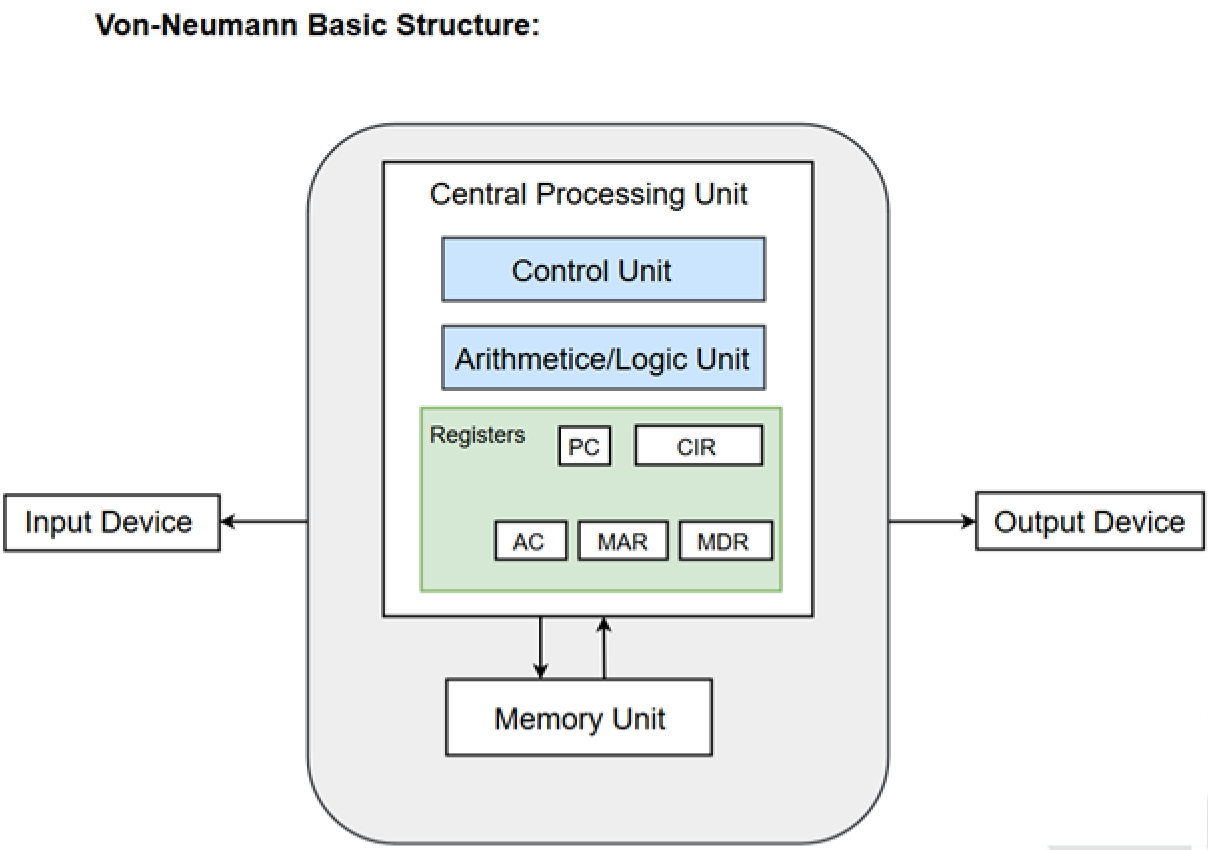
- **Computer Architecture** focuses on the logical design, including instruction sets, addressing modes, and how software interacts with hardware.
- **Computer Organization** deals with the actual physical components and how they function together to execute instructions.

In simple terms:

- **Architecture is about design and planning (what to do).**
- **Organization is about implementation and execution (how to do it).**

Understanding computer organization helps in optimizing system performance, selecting the right hardware, and improving computational efficiency.

1.1.2: The von Neumann Architecture



The **von Neumann Architecture** is a foundational computer architecture model proposed by **John von Neumann** in 1945. It serves as the basis for most modern computers, where a single memory system is used to store both **instructions (programs)** and **data**.

Key Features of the von Neumann Architecture

1. **Stored Program Concept:**
   - Both the program instructions and data are stored in the same memory unit.
   - Instructions are fetched and executed sequentially.
2. **Single Memory for Instructions and Data:**
   - Unlike earlier computing models where instructions were hardwired or stored separately, von Neumann architecture stores everything in a single memory.
3. **Central Processing Unit (CPU):**
   - The CPU consists of:
     - **Control Unit (CU):** Directs the execution of instructions.

        - **Arithmetic Logic Unit (ALU):** Performs calculations and logical operations.
        - **Registers:** Small, high-speed memory locations for temporary data storage.
4. **Sequential Execution of Instructions:**
    - Instructions are processed **one at a time** in a cycle:
        - Fetch → Decode → Execute → Store
5. **Use of Buses for Communication:**
    - The system uses three main buses for data transfer:
        - **Data Bus** – Transfers actual data.
        - **Address Bus** – Carries memory addresses.
        - **Control Bus** – Manages signals between components.

Von Neumann Cycle (Fetch-Decode-Execute Cycle)

Every instruction in a von Neumann-based system follows a cycle:

1. **Fetch:** The CPU retrieves an instruction from memory.
2. **Decode:** The instruction is interpreted by the Control Unit.
3. **Execute:** The instruction is carried out by the ALU or other components.
4. **Store:** The result is saved back to memory or a register.

This cycle repeats continuously while the computer is running.

Advantages of von Neumann Architecture

- **Simplicity:** Uses a single memory for both data and instructions, making hardware design straightforward.
- **Flexibility:** Programs can be modified easily since they are stored in memory.
- **Efficient Use of Memory:** Eliminates the need for separate instruction storage.

Disadvantages of von Neumann Architecture

- **Von Neumann Bottleneck:** Since both instructions and data share the same memory and bus, only one can be accessed at a time, slowing down execution.
- **Memory Latency:** The CPU may wait for memory access, reducing efficiency.

- **Security Risks:** Storing both data and instructions in the same memory can lead to vulnerabilities like code injection attacks.

Comparison with Harvard Architecture

While von Neumann architecture uses a single memory for both instructions and data, **Harvard Architecture** separates them into different memory units. This allows for faster processing but makes hardware more complex.

Most modern computers still follow the von Neumann model but incorporate elements of Harvard architecture, such as separate caches for data and instructions.

1.1.3: Major Functional Units

A computer system consists of several **functional units** that work together to process data and execute instructions. These units can be broadly classified into the following:

1. Central Processing Unit (CPU)

The **CPU** is the brain of the computer, responsible for executing instructions and managing data flow within the system. It consists of three key components:

a. Control Unit (CU)

- Directs the operation of the computer by fetching, decoding, and executing instructions.
- Controls the flow of data between different components.
- Manages the system's buses for communication.

b. Arithmetic Logic Unit (ALU)

- Performs arithmetic operations (addition, subtraction, multiplication, division).
- Handles logical operations (AND, OR, NOT, XOR).
- Processes comparison operations used in decision-making.

c. Registers

- Small, high-speed memory locations inside the CPU.
- Store data temporarily for quick access.
- Examples include:
  - **Accumulator (ACC):** Holds intermediate arithmetic results.
  - **Program Counter (PC):** Keeps track of the next instruction.
  - **Instruction Register (IR):** Stores the current instruction being executed.

2. Memory Unit

The memory unit stores data, instructions, and intermediate results needed for processing. It is divided into:

a. Primary Memory (Main Memory/RAM)

- Holds data and instructions that the CPU is currently using.
- Provides fast access but is volatile (loses data when power is off).
- Examples: **RAM (Random Access Memory) and Cache Memory**.

b. Secondary Memory (Storage Devices)

- Provides long-term data storage.
- Examples: **Hard Drives (HDDs), Solid-State Drives (SSDs), Flash Drives, and Memory Cards**.

c. Cache Memory

- A small, high-speed memory located close to the CPU.
- Stores frequently accessed data and instructions to speed up processing.

3. Input Unit

- Accepts user inputs and converts them into machine-readable form.
- Examples: **Keyboard, Mouse, Microphone, Scanner, Touchscreen**.

4. Output Unit

- Converts processed data into a human-readable format.

- Examples: **Monitor (for visual display), Printer, Speakers, Projectors**.

5. Bus System

Buses are communication pathways that transfer data between different components. There are three types:

- **Data Bus:** Carries actual data between the CPU, memory, and I/O devices.
- **Address Bus:** Transfers memory addresses for data storage and retrieval.
- **Control Bus:** Sends control signals to manage operations and synchronization.

6. Input/Output (I/O) Controllers

- Manage communication between the CPU and external devices.
- Handle device-specific processing to reduce the CPU's workload.

7. Power Supply Unit (PSU)

- Converts electrical power from an external source into a form usable by the computer.
- Provides the necessary voltage and current to different components.

Summary

In this lesson, we have learnt that;

Computer architecture and organization define how computers function at the hardware and software levels. Organization focuses on hardware components like the CPU, memory, and buses, while architecture deals with logical design aspects like instruction sets. The von Neumann architecture, introduced in 1945, forms the foundation of modern computers by using a single memory system for instructions and data. Its advantages include simplicity and flexibility, but it suffers from the "von Neumann bottleneck." The lesson also covers the CPU’s major functional units, including the ALU, control unit, registers, and buses, which work together to execute instructions.

Self-Assessment Questions (SAQs) for Lesson 1

Now that you have completed this lesson, you can assess how well you have achieved its Learning Outcomes by answering these questions. You can check your answers with the Notes on the Self-Assessment Questions at the end of this module.

SAQ 1.1 (Testing Learning Outcome 1)

What is the primary distinction between computer organization and computer architecture?

SAQ 1.2 (Testing Learning Outcome 2)

Why is the von Neumann architecture widely used despite its limitations?

Notes on SAQs for Lesson 1

SAQ 1.1

Computer organization deals with the physical aspects of a computer, including how hardware components such as the CPU, memory, and buses interact to execute programs. It focuses on system implementation and efficiency. In contrast, computer architecture refers to the logical structure and design, including instruction sets, addressing modes, and how software interacts with hardware. While architecture defines "what" a system should do, organization determines "how" it accomplishes those tasks. Together, they influence performance, cost, and system capabilities.

SAQ 1.2

The von Neumann architecture is popular due to its simplicity and efficiency. By using a single memory system for both data and instructions, it simplifies hardware design and allows programs to be modified easily. Additionally, it enables general-purpose computing, making it applicable to various applications. However, its major drawback is the "von Neumann bottleneck," where shared memory access slows down processing speed. Despite this limitation, modern optimizations like caches and pipelining help mitigate its impact, ensuring its continued relevance in computing.