UNIT (two) Computer Hardware

The Central Processing Unit (Control Unit, Arithmetic and Logic Unit, Main Memory). Peripherals. The organization of a simple computer. The storage of programs and data. Data and Control paths in the computer (buses or highways). The Fetch- execute Cycle.

Why this chapter

The computer as a machine consists of different components that interact with each other to provide the desired functionality of the computer. As a user of the computer, we need to be aware of the main components of the computer, their functions and the interconnection between the different components of the computer. This chapter describes the different hardware components of the computer.

Introduction:

When we talk of computer hardware, the three related terms that require introduction are— **computer architecture, computer organization and computer design**. Computer architecture refers to the structure and behavior of the computer. It includes the specifications of the components, for example, instruction format, instruction set and techniques for addressing memory, and how they connect to the other components. Given the components, computer organization focuses on the organizational structure. It deals with how the hardware components operate and the way they are connected to form the computer. Given the system specifications, computer design focuses on the hardware to be used and the interconnection of parts. Different kinds of computer, such as a PC or a mainframe computer may have different organization; however, basic organization of the computer remains the same.

A computer consists of three main components—(1) Input/Output (I/O) Unit, (2) Central Processing Unit (CPU), and (3) Memory Unit. The computer user interacts with the computer via the I/O unit. The purpose of I/O unit is to provide data and instructions as input to the computer and to present relevant information as output from the computer. CPU controls the operations of the computer and processes the received input to generate the relevant output. The memory unit stores the instructions and the data during the input activity, to make instructions readily available to CPU during processing. It also stores the processed output. This chapter discusses the hardware components of the computer and the interaction between them.

The Central Processing Unit:

Central Processing Unit (CPU) or the processor is also often called the brain of computer. CPU consists of Arithmetic Logic Unit (ALU) and Control Unit (CU).

In addition, CPU also has a set of registers which are temporary storage areas for holding data, and instructions.

ALU performs the arithmetic and logic operations on the data that is made available to it.

CU is responsible for organizing the processing of data and instructions. CU controls and coordinates the activity of the other units of computer. CPU uses the registers to store the data, instructions during processing.

CPU executes the stored program instructions, i.e. instructions and data are stored in memory before execution. For processing, CPU gets data and instructions from the memory. It interprets the program instructions and performs the arithmetic and logic operations required for the processing of data. Then, it sends the processed data or result to the memory. CPU also acts as an administrator and is responsible for supervising operations of other parts of the computer.

The CPU is fabricated as a single Integrated Circuit (IC) chip, and is also known as the microprocessor. The microprocessor is plugged into the motherboard of the computer (Motherboard is a circuit board that has electronic circuit etched on it and connects the microprocessor with the other hardware components).

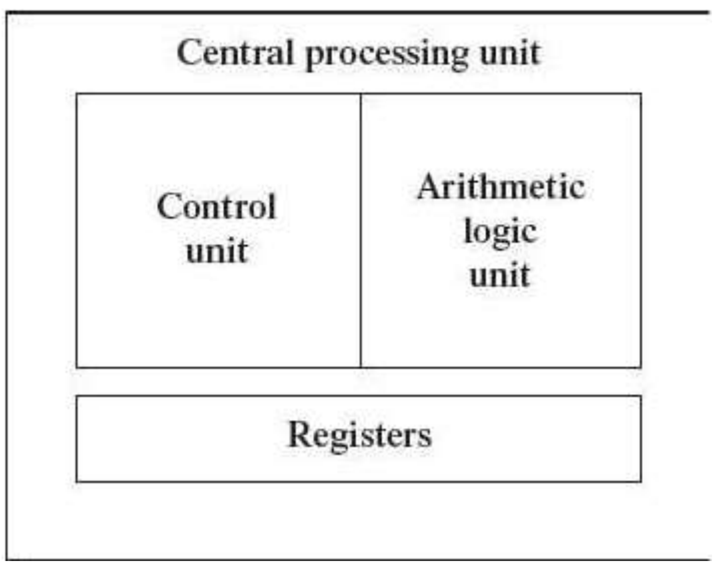


Fig: CPU

1. **<u>Arithmetic Logic Unit:</u>**
   - ALU consists of two units—arithmetic unit and logic unit.

- The arithmetic unit performs arithmetic operations on the data that is made available to it. Some of the arithmetic operations supported by the arithmetic unit are—addition, subtraction, multiplication and division.
- The logic unit of ALU is responsible for performing logic operations. Logic unit performs comparisons of numbers, letters and special characters. Logic operations include testing for greater than, less than or equal to condition.
- ALU performs arithmetic and logic operations, and uses registers to hold the data that is being processed.

2. **<u>Control Unit:</u>**
    - The control unit of a computer does not do any actual processing of data. It organizes the processing of data and instructions. It acts as a supervisor and, controls and coordinates the activity of the other units of computer.
    - CU coordinates the input and output devices of a computer. It directs the computer to carry out stored program instructions by communicating with the ALU and the registers. CU uses the instructions in the Instruction Register (IR) to decide which circuit needs to be activated. It also instructs the ALU to perform the arithmetic or logic operations. When a program is run, the Program Counter (PC) register keeps track of the program instruction to be executed next.
    - CU tells when to fetch the data and instructions, what to do, where to store the results, the sequencing of events during processing etc.
    - CU also holds the CPU's Instruction Set, which is a list of all operations that the CPU can perform.

The function of a (CU) can be considered synonymous with that of a conductor of an orchestra. The conductor in an orchestra does not perform any work by itself but manages the orchestra and ensures that the members of orchestra work in proper coordination.

<u>Memory Unit(Primary memory):</u>

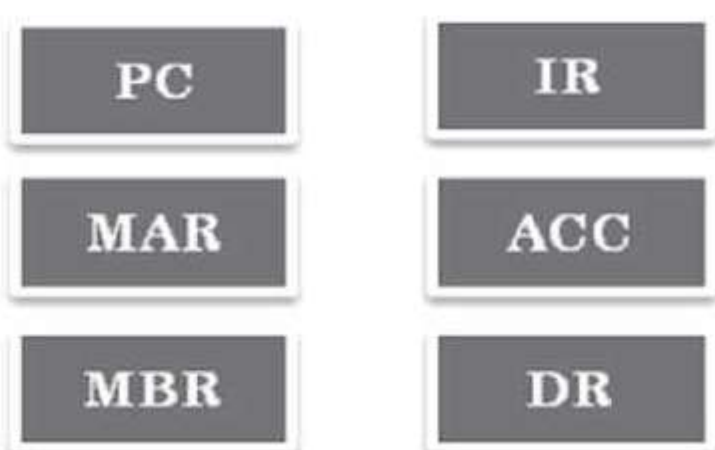
The memory unit consists of **registers, cache memory and primary memory**. Primary memory or main memory of the computer is used to store the data and instructions during execution of the instructions. Random Access Memory (RAM) and Read Only Memory (ROM) are the primary memory. In addition to the main memory, there is another kind of storage device known as the secondary memory. Secondary memory is non-volatile and is used for permanent storage of data and programs. A program or data that has to be executed is brought into the RAM from the secondary memory.

Registers:

- Registers are high-speed storage areas within the CPU, but have the least storage capacity. Registers are not referenced by their address, but are directly accessed and manipulated by the CPU during instruction execution.
- Registers store data, instructions, addresses and intermediate results of processing. Registers are often referred to as the CPU's working memory.
- The data and instructions that require processing must be brought in the registers of CPU before they can be processed. For example, if two numbers are to be added, both numbers are brought in the registers, added and the result is also placed in a register.
- Registers are used for different purposes, with each register serving a specific purpose.

Some of the important registers in CPU are as follows—

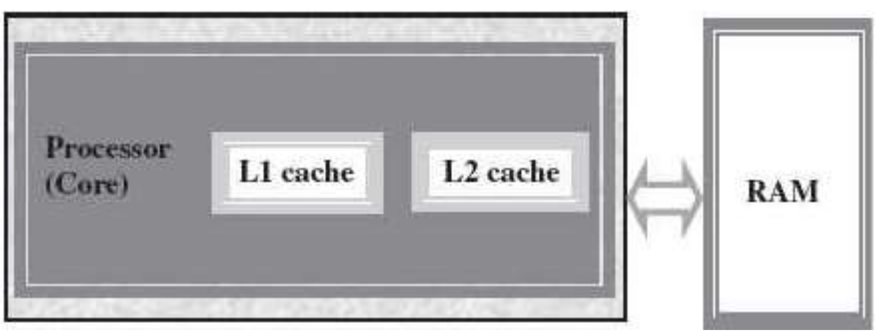
- ✓ **Accumulator (ACC)** stores the result of arithmetic and logic operations.
- ✓ **Instruction Register (IR)** contains the current instruction most recently fetched.
- ✓ **Program Counter (PC)** contains the address of next instruction to be processed.
- ✓ **Memory Address Register (MAR)** contains the address of next location in the memory to be accessed.
- ✓ **Memory Buffer Register (MBR)** temporarily stores data from memory or the data to be sent to memory.
- ✓ **Data Register (DR)** stores the operands and any other data.



The number of registers and the size of each (number of bits) register in a CPU helps to determine the power and the speed of a CPU. The overall number of registers can vary from about ten to many hundreds, depending on the type and complexity of the processor. The size of register, also called word size, indicates the amount of data with which the computer can work at any given time. The bigger the size, the more quickly it can process data. The size of a register may be 8, 16, 32 or 64 bits. For example, a 32–bit CPU is one in which each register is 32 bits wide and its CPU can manipulate 32 bits of data at a time. Nowadays, PCs have 32–bit or 64–bit registers. 32-bit processor and 64-bit processor are the terms used to refer to the size of the registers. Other factors remaining the same, a 64-bit processor can process the data twice as fast as one with 32-bit processor.

Cache Memory:

- The data and instructions that are required during the processing of data are brought from the secondary storage devices and stored in the RAM. For processing, it is required that the data and instructions are accessed from the RAM and stored in the registers. The time taken to move the data between RAM and CPU registers is large. This affects the speed of processing of computer, and results in decreasing the performance of CPU.
- Cache memory is a very high speed memory placed in between RAM and CPU. Cache memory increases the speed of processing.
- Cache memory is a storage buffer that stores the data that is used more often, temporarily, and makes them available to CPU at a fast rate. During processing, CPU first checks cache for the required data. If data is not found in cache, then it looks in the RAM for data.
- To access the cache memory, CPU does not have to use the motherboard's system bus for data transfer. (The data transfer speed slows to the motherboard's capability, when data is passed through system bus. CPU can process data at a much faster rate by avoiding the system bus.)



- Cache memory is built into the processor, and may also be located next to it on a separate chip between the CPU and RAM. Cache built into the CPU is faster than separate cache, running at the speed of the microprocessor itself. However, separate cache is roughly twice as fast as RAM.
- The CPU has a built-in Level 1 (L1) cache and Level2 (L2) cache, as shown in above figure. In addition to the built-in L1 and L2 cache, some CPUs have a separate cache chip on the motherboard. This cache on the motherboard is called Level 3 (L3) cache. Nowadays, high-end processor comes with built-in L3 cache, like in Intel core i7. The L1, L2 and L3 cache store the most recently run instructions, the next ones and the

possible ones, respectively. Typically, CPUs have cache size varying from 256KB (L1), 6 MB (L2), to 12MB (L3) cache.

- Cache memory is very expensive, so it is smaller in size. Generally, computers have cache memory of sizes 256 KB to 2 MB.

Primary Memory (main memory)

- Primary memory is the main memory of computer. It is used to store data and instructions during the processing of data. Primary memory is semiconductor memory.
- Main memory is of two kinds—Random Access Memory (RAM) and Read Only Memory (ROM).
- **RAM** is volatile. It stores data when the computer is on. The information stored in RAM gets erased when the computer is turned off. RAM provides temporary storage for data and instructions.
- **ROM** is non-volatile memory, but is a read only memory. The storage in ROM is permanent in nature, and is used for storing standard processing programs that permanently reside in the computer. ROM comes programmed by the manufacturer.
- RAM stores data and instructions during the execution of instructions. The data and instructions that require processing are brought into the RAM from the storage devices like hard disk. CPU accesses the data and the instructions from RAM, as it can access it at a *fast* speed than the storage devices connected to the input and output unit.
- The input data that is entered using the input unit is stored in RAM, to be made available during the processing of data. Similarly, the output data generated after processing is stored in RAM before being sent to the output device. Any intermediate results generated during the processing of program are stored in RAM.
- RAM provides a limited storage capacity, due to its high cost.

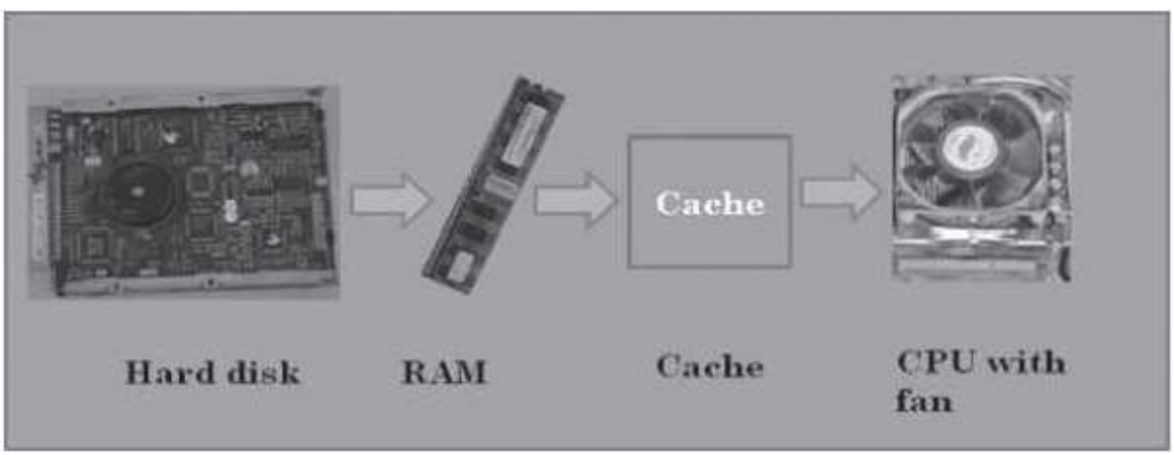


Fig:Interaction of CPU with memory

<u>Peripherals:</u>

Computer peripherals are the devices you use to expand your system's functionality and are not essential for the computer to work. Many peripherals are external devices that give you a way to input information. For example, you might use a mouse or trackpad to navigate the screen, a keyboard to type text or a microphone to record audio. Other peripherals are output devices that let you see, print or listen to something, such monitors, printers and speakers. While debatable since they are key components for a functional computer, internal devices like hard drives and memory may be considered peripherals.

The organization of a simple computer

(In unit one**)**

<u>The storage of programs and data:</u>

Storing the data and instructions in a same memory is called as stored program concept. This approach concept' was first adopted by **John Von Neumann** and such architecture is named as von-Neumann architecture. The idea behind the Von Neumann architectures is the ability to store instructions in the memory along with the data on which the instructions operate.

The Von Neumann architecture consists of three distinct components: a central processing unit, memory unit and input/output (I/O) interfaces. CPU consists of control unit and arithmetic and logic unit (ALU). ALU is responsible for carrying out all arithmetic and logical operations on data where as control unit determines the order of flow of instructions that need to be executed in programs by issuing control signals to the hardware.

The memory unit consists of RAM (Read/Write memory), which is the main memory used to store program data and instructions. The I/O interfaces allows the users to communicate with the outside world such as storage devices.

<u>System Bus:</u>

It is a communication path between the microprocessor and peripherals; it is nothing but a group of wires to carry bits.

<u>Bus organization</u>

Bus is a common channel through which bits from any sources can be transferred to the destination. A typical digital computer has many registers and paths must be provided to transfer instructions from one register to another. The number of wires will be excessive if separate lines are used between each register and all other registers in the system. A more efficient scheme for transferring information between registers in a multiple register configuration is a common bus 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.

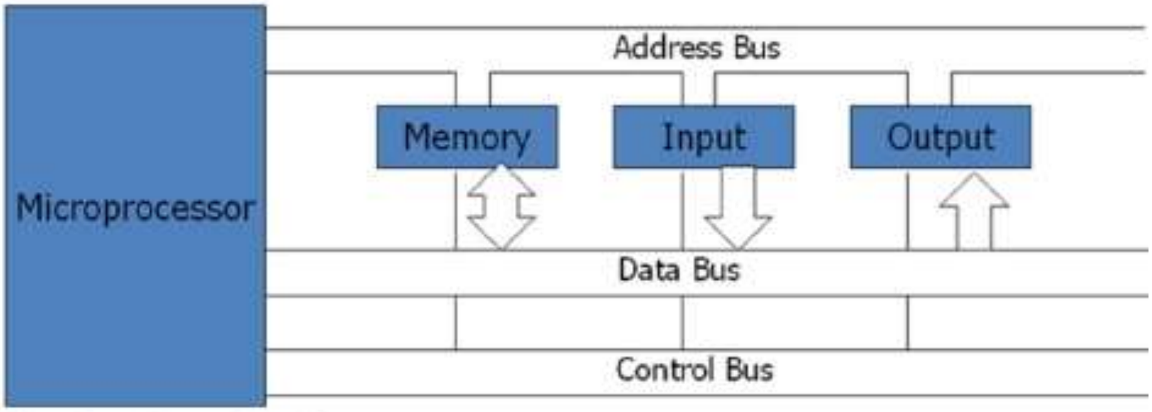


Fig: Bus Organization

A very easy way of constructing a common bus system is with multiplexers. The multiplexers select the source register whose binary information is then pleased on the bus.

A system bus consists of about 50 to 100 of separate lines each assigned a particular meaning or function. Although there are many different bus designers, on any bus, the lines can be classified into three functional groups; data, address and control lines. In addition, there may be power distribution lines as well.

Address Bus

It is a group of conducting wires which carries address only. Address bus is unidirectional because data flow in one direction, from microprocessor to memory or from microprocessor to Input/output devices (That is, Out of Microprocessor).
The Length of the address bus determines the amount of memory a system can address. Such as a system with a 32-bit address bus can address 2^{32} memory locations.

Data Bus

It is a group of conducting wires which carries data only. Data bus is bidirectional because data flow in both directions from microprocessor to memory or Input/Output devices and from memory or Input/Output devices to microprocessor.

Control Bus

It is a group of conducting wires, which is used to generate timing and control signals to control all the associated peripherals. The control lines are used to control the access to and the use of the data and address lines. Because data and address lines are shared by all components, there must be a means of controlling their use. Some control signals are:

→Memory read → I/O read

→I/O Write →Memory write

→ Opcode fetch

The Fetch- execute Cycle (INSTRUCTION CYCLE):

The primary responsibility of a computer processor is to execute a sequential set of instructions that constitute a program. CPU executes each instruction in a series of steps, called instruction cycle. A instruction cycle involves four steps.

- **Fetching** The processor fetches the instruction from the memory. The fetched instruction is placed in the Instruction Register. Program Counter holds the address of next instruction to be fetched and is incremented after each fetch.
- **Decoding** The instruction that is fetched is broken down into parts or decoded. The instruction is translated into commands so that they correspond to those in the CPU's instruction set. The instruction set architecture of the CPU defines the way in which an instruction is decoded.
- **Executing** The decoded instruction or the command is executed. CPU performs the operation implied by the program instruction. For example, if it is an ADD instruction, addition is performed.
- **Storing** CPU writes back the results of execution, to the computer's memory.

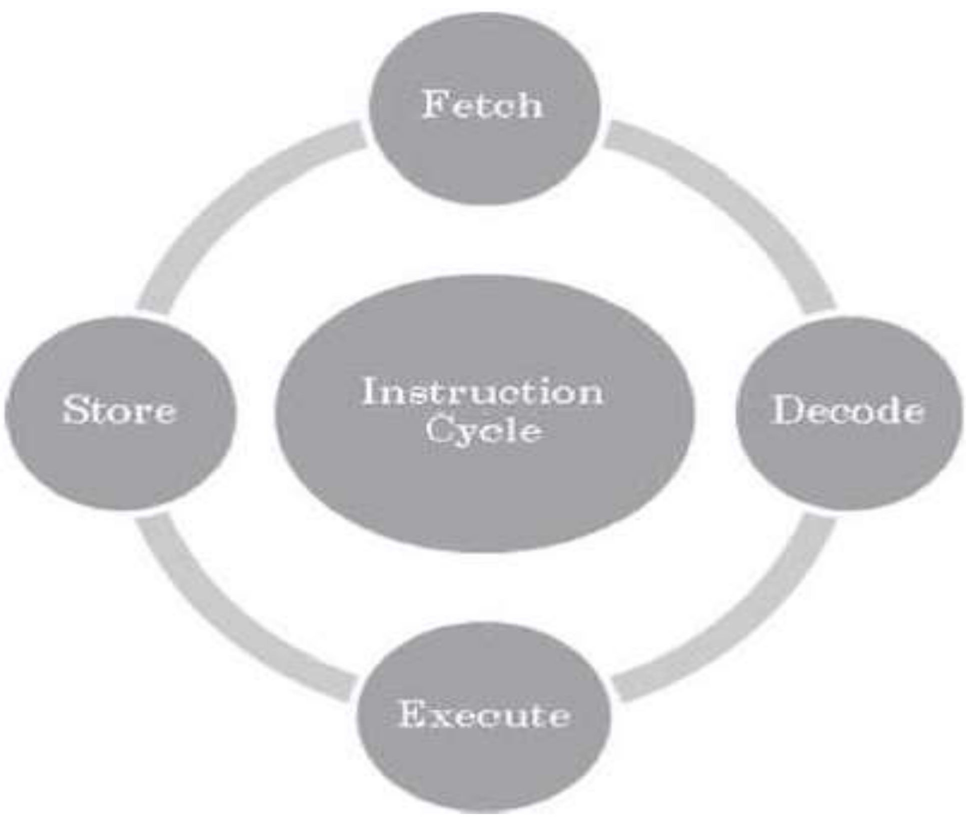
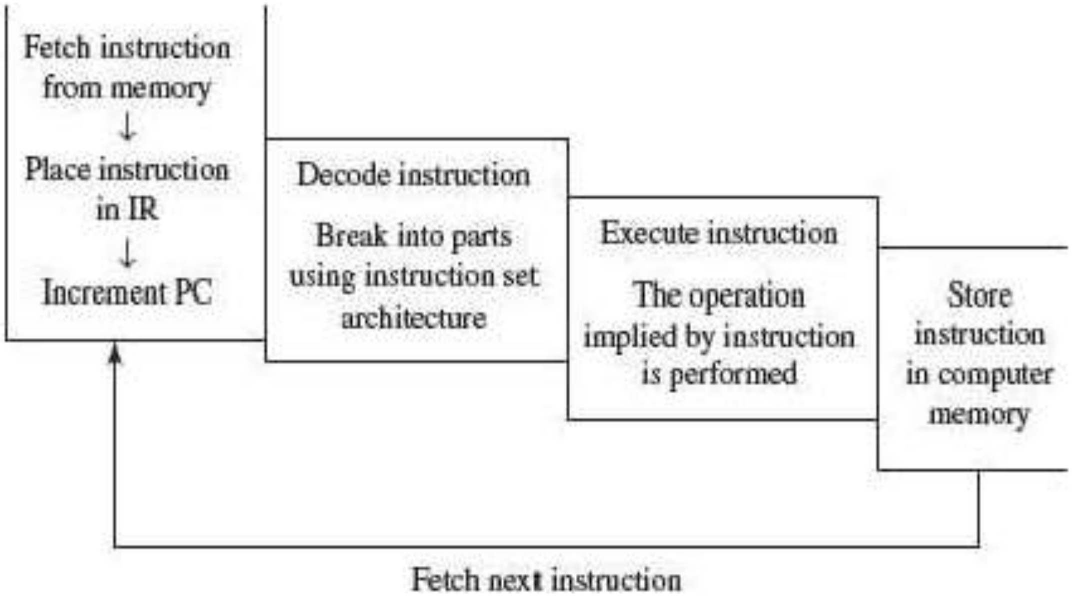


Figure: Instruction cycle



Instructions are of different categories. Some categories of instructions are—

- Memory access or transfer of data between registers.
- Arithmetic operations like addition and subtraction.
- Logic operations such as AND, OR and NOT.
- Control the sequence, conditional connections, etc.

A CPU performance is measured by the number of instructions it executes in a second, i.e., MIPS (million instructions per second), or BIPS (billion instructions per second).