Chapter – 1
Introduction

1.1 Introduction

A Microprocessor is a multipurpose programmable, clock driven, register based electronic device that reads binary instructions from a storage device called memory, accepts binary data as input, processes data according to those instructions and provide results as output. The microprocessor operates in binary 0 and 1 known as bits are represented in terms of electrical voltages in the machine that means 0 represents low voltage level and 1 represents high voltage level. Each microprocessor recognizes and processes a group of bits called the word and microprocessors are classified according to their word length such as 8 bits microprocessor with 8 bit word and 32 bit microprocessor with 32 bit word etc.

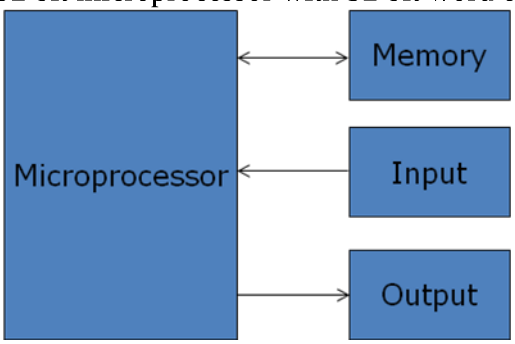

Fig 1.1: A Programmable Machine

<u>Terms used</u>

- CPU: - Central processing unit which consists of Arithmetic Logic Unit and Control Unit.
- Microprocessor: - Single chip consisting of all units of CPU.
- Microcomputer: - Computer having microprocessor as CPU.
- Microcontroller: - Single chip consisting of MPU, memory, I/O and interfacing circuits.
- MPU: - Microprocessing Unit – Complete processing unit with the necessary control signals.

1.2 Basic Block Diagram of a Computer

Traditionally, the computer is represented with four components such as memory, input, output and central processing unit (CPU) which consists of arithmetic logic unit (ALU) and control unit (CU).

The CPU contains various registers to store data, the ALU to perform arithmetic and logical operations, instruction decoders, counters and control lines. The CPU reads instructions from memory and performs the tasks specified. It communicates with input/output (I/O) devices either to accept or to send data, the I/O devices is known as peripherals.

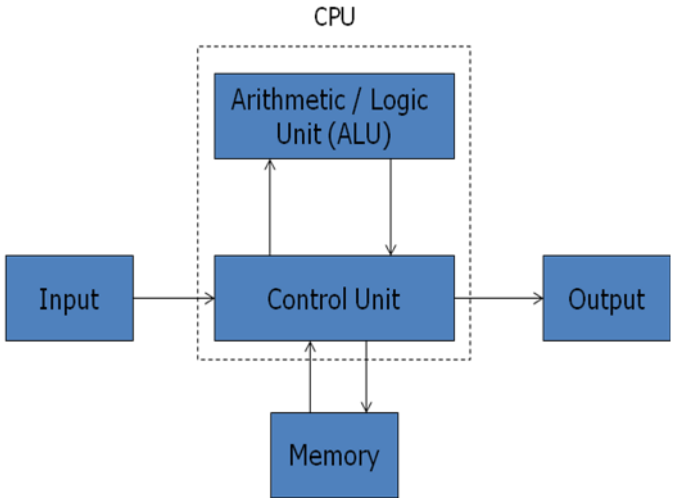

Fig 1.2 (a): Traditional Block diagram of a computer

Later on around late 1960's, traditional block diagram can be replaced with computer having microprocessor as CPU which is known as microcomputer. Here CPU was designed using integrated circuit technology (IC's) which provided the possibility to build the CPU on a single chip.

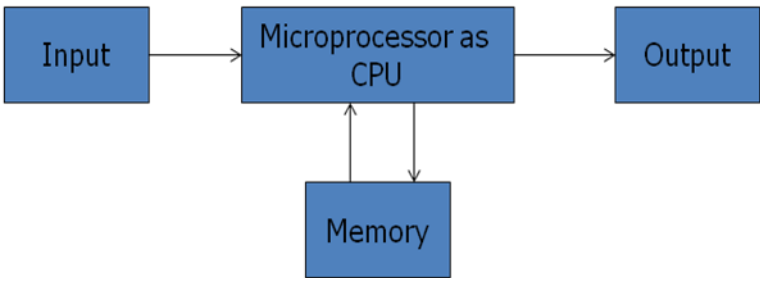

Fig 1.2 (b): Block Diagram of a computer with the Microprocessor as CPU

Later on semiconductor fabrication technology became more advanced, manufacturers were able to place not only MPU but also memory and I/O interfacing circuits on a single chip known as microcontroller, which also includes additional devices such as A/D converter, serial I/O, timer etc.

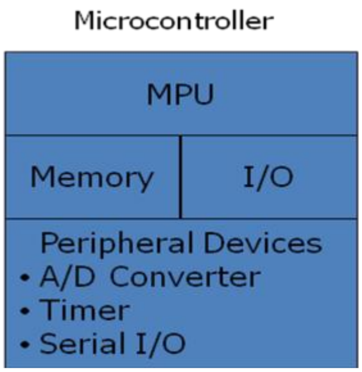

Fig 1.2 (c): Block Diagram of a Microcontroller

1.3 Organization of a microprocessor based system

Microprocessor based system includes there components microprocessor, input/output and memory (RAM and ROM). These components are organized around a common communication path called a bus.

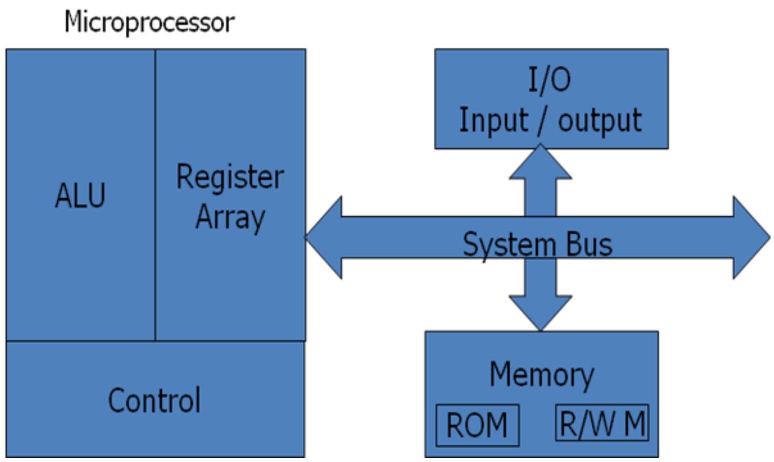

Fig 1.3: Microprocessor Based System with Bus Architecture

Microprocessor:

It is clock driven semiconductor device consisting of electronic logic circuits manufactured by using either a large scale integration (LSI) or very large scale integration (VLSI) technique. It is capable of performing various computing functions and making decisions to change the sequence of program execution. It can be divided in to three segments.

A. Arithmetic/Logic unit: It performs arithmetic operations as addition and subtraction and logic operations as AND, OR & XOR.
B. Register Array: The registers are primarily used to store data temporarily during the execution of a program and are accessible to the user through instruction. The registers can be identified by letters such as B, C, D, E, H and L.
C. Control Unit: It provides the necessary timing and control signals to all the operations in the microcomputer. It controls the flow of data between the microprocessor and memory and peripherals.

Memory:

Memory stores binary information such as instructions and data, and provides that information to the up whenever necessary. To execute programs, the microprocessor reads instructions and data from memory and performs the computing operations in its ALU. Results are either transferred to the output section for display or stored in memory for later use. Memory has two sections.

A. Read only Memory (ROM): Used to store programs that do not need alterations and can only read.
B. Read/Write Memory (RAM): Also known as user memory which is used to store user programs and data. The information stored in this memory can be easily read and altered.

Input/Output:

- It communicates with the outside world using two devices input and output which are also Known as peripherals.
- The input device such as keyboard, switches, and analog to digital converter transfer binary information from outside world to the microprocessor.
- The output devices transfer data from the microprocessor to the outside world. They include the devices such as LED, CRT, digital to analog converter, printer etc.

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

1.4 Bus organization

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.

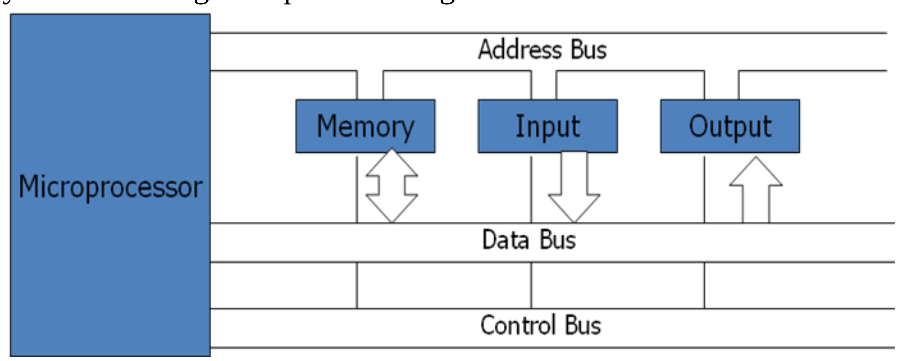

Fig. 1.4: Bus Organization

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.

- The data lines provide a path for moving data between system modules. These lines are collectively called data bus.
- The address lines are used to designate the source/destination of data on data bus.
- 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. Control signals transmit both command and timing signals indicate the

validity of data and address information. Command signals specify operations to be performed. Control lines include memory read/write, I/O read/write, bus request, bus grant, clock, reset, interrupt request, interrupt acknowledge etc.

Historical Background of the Development of Computers:
The most efficient and versatile electronic machine computer is basically a development of a calculator which leads to the development of the computer. The older computer were mechanical and newer are digital. The mechanical computer namely difference engine and analytical engine developed by Charles Babbage the father of the computer can be considered as the forerunners of modern digital computers.

The difference engine was a mechanical device that could add and subtract and could only run a single algorithm. Its output system was incompatible to write on punched cards and early optical disks. The 'analytical engine' provided more advanced features. It consisted mainly four components the store (memory), the mill (computation unit), input section (punched card reader) and output section (punched and printed output). The store consisted of 1000s of words of 50 decimal digits used to hold variables and results. The mill could accept operands from the store, add, subtract, multiply or divide them and return a result to the store.

The evolution of the vacuum tubes led the development of computer into a new era. The world's first general purpose electronic digital computer was ENIAC (Electronic Numerical Integrator and Calculator) built by using vacuum tubes was enormous in size and consumed very high power. However it was faster than mechanical computers. The ENIAC was decimal machine and performed only decimal numbers. Its memory consisted of 20 'accumulators' each capable of holding 10 digits decimal numbers. Each digit was represented by a ring of 10 vacuum tubes. ENIAC had to be programmed manually by setting switches and plugging and unplug a cable which was the main drawback of it.

Automated calculator:
It is a data processing device that carries out logic and arithmetic operations but has limited programming capability for the user. It accepts data from a small keyboard one digit at a time performs required arithmetic and logical calculations and stores the result on visual display like LCD or LED. The calculator's programs are stored in ROM's while the data is stored in RAM.
Some important features of automated calculations:

- The ability to interface easily with keyboards and displays.
- The ability to handle decimal digits, the device is able to handle more than 4 bits at a time.
- Ability to execute the standard programs stored in read only memory.
- Extendibility, so that mathematical functions such as %, √, trigonometric, statistical etc. can be easily executed.
- Flexibility so it can be used in engineering business or programming without a complete new design.
- Low cost, small size and low power consumptions.

1.5 Stored Program Concept and Von-Neumann Machine:

The simplest way to organize a computer is to have one processor, register and instruction code format with two parts op-code and address/operand. The memory address tells the control where to find an operand in memory. This operand is read from memory and used as data to be operated on together with the data stored in the processor register. Instructions are stored in one section of same memory. It is called stored program concept.

The task of entering and altering the programs for ENIAC was tedious. It could be facilitated if the program could be represented in a form suitable for storing in memory alongside the data. So the computer could get its instructions by reading from the memory and program could be set or altered by setting the values of a portion of memory. This approach is known as 'stored- program concept' was first adopted by John Von Neumann and such architecture is named as von-Neumann architecture and shown in figure below.

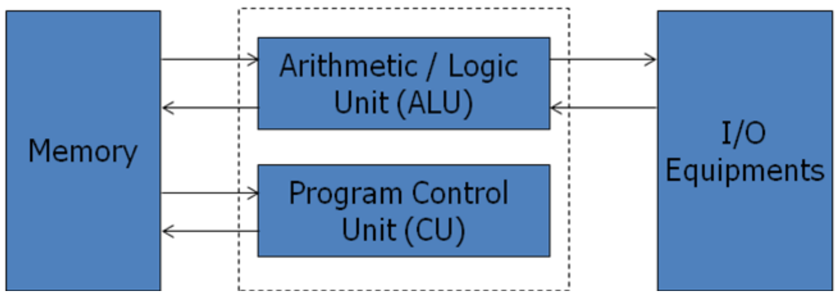

Fig. 1.5: Von –Neumann Architecture

The main memory is used to stare both data and instructions. The arithmetic and logic unit is capable of performing arithmetic and logical operation on binary data. The program control unit interprets the instruction in memory and causes them to be executed. The I/O unit gets operated from the control unit.

The Von–Neumann architecture is the fundamental basis for the architecture of modern digital computers. It consisted of 1000 storage locations which can hold words of 40 binary digits and both instructions as well as data are stored in it. The storage location of control unit and ALU are called registers and the various models of registers are:

- **MAR** – memory address register – contains the address in memory of the word to be written into or read from MBR.
- **MBR** – memory buffer register – consists of a word to be stored in or received from memory.
- **IR** – instruction register – contains the 8-bit op-code instruction to be executed.
- **IBR** – instruction buffer register – used to temporarily hold the instruction from a word in memory.
- **PC** - program counter - contains the address of the next instruction to be fetched from memory.
- **AC & MQ** (Accumulator and Multiplier Quotient) - holds the operands and results of ALU after processing.

Harvard Architecture

In von-Neumann architecture, the same memory is used for storing instructions and data. Similarly, a single bus called data bus or address bus is used for reading data and instructions from or writing to memory. It also had limited the processing speed for computers.

The Harvard architecture based computer consists of separate memory spaces for the programs (instructions and data). Each space has its own address and data buses. So instructions and data can be fetched from memory concurrently and provides significance processing speed improvement.

In figure below, there are two data and two address buses multiplexed for data bus and address bus. Hence, there are two blocks of RAM chips one for program memory and another for data memory addresses.

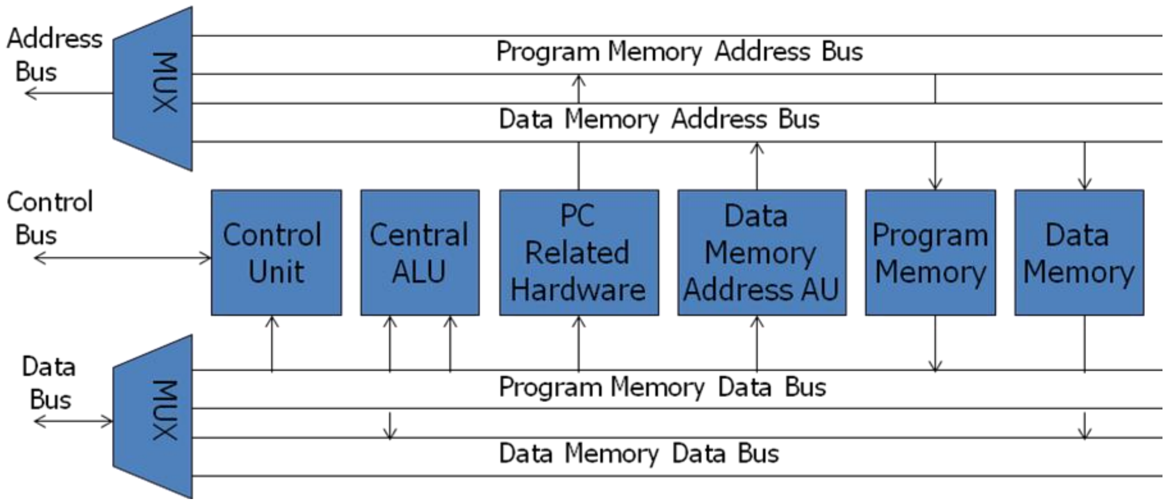

Fig. 1.6: Harvard Architecture Based Microprocessor

The control unit controls the sequence of operations. Central ALU consists of ALU, multiplier, accumulator and scaling chief register. The PC used to address program memory and always contains the address of next instruction to be executed. Here data and control buses are bidirectional and address bus is unidirectional.

Evolution of Microprocessors (Intel series)

The CPU of a computer consists of ALU, CU and memory. If all these components can be organized on a single chip by means of SSI, MSI, LSI, VLSI, ULSI, ELSI technology, then such chip is called microprocessor. It can fetch instructions from memory, decode and execute them, perform logical and arithmetic functions, accept data from input devices and send results to the output devices. The evolution of microprocessor is dependent on the development of integrated circuit technology from Single Scale Integration (SSI) to Giga Scale Integration (GSI).

Date	Microprocessor	Data bus	Address Bus	Memory

1971	4004	4-bit	10-bit	640 Bytes
1972	8008	8-bit	14-bit	16k
1974	8080	8bit	16bit	64k
1976	8085	8bit	16b it	64k
1978	8086	16bit	20bit	1M
1979	8088	8bit	20bit	1M
1982	80286	16bit	24bit	16M
1985	80386	32bit	32bit	4G
1989	80486	32bit	32bit	4G
1993	Pentium	32/64bit	32bit	4G
1995	Pentium pro	32/64bit	36bit	64G
1997	Pentium II	64bit	36bit	64G
1998	Celeron	64bit	36bit	64G
1999	Pentium III	64bit	36bit	64G
2000	Pentium IV	64bit	36bit	64G
2001	Itanium	128 bit	64bit	64G
2002	Itanium 2	128 bit	64bit	64G
2003	Pentium M/Centrino (wireless capability) for Mobile version e.g. Laptop			
	Core 2: X86 – 64 Architecture			

1.6 Processing Cycle of a Stored Program Computer

- Fetch
- Identify
- Fetch Data
- Process
- Write Back

1.7 Microinstructions and Hardwired/ Microprogrammed Control Unit

Micro-Operations

- A computer executes a program consisting instructions. Each instruction is made up of shorter sub-cycles as fetch, indirect, execute cycle, and interrupt.
- Performance of each cycle has a number of shorter operations called micro-operations.
- Called so because each step is very simple and does very little.
- Thus micro-operations are functional atomic operation of CPU.
- Hence events of any instruction cycle can be described as a sequence of micro-operations.

Microinstructions

Each instruction is characterized with many machine cycles and each cycle is characterized with many T-states. The lower instruction level patterns which are the numerous sequences for a single instruction are known as microinstructions. Suppose we can visualize the microinstruction with the help of fetch cycle, or read cycle or write cycle.

Fetch – Registers

- Memory Address Register (MAR)
  - Connected to address bus
  - Specifies address for read or write op
- Memory Buffer Register (MBR)
  - Connected to data bus
  - Holds data to write or last data read
- Program Counter (PC)
  - Holds address of next instruction to be fetched
- Instruction Register (IR)
  - Holds last instruction fetched

Fetch Sequence

- Address of next instruction is in PC
- Address (MAR) is placed on address bus
- Control unit issues READ command
- Result (data from memory) appears on data bus
- Data from data bus copied into MBR
- PC incremented by 1 (in parallel with data fetch from memory)
- Data (instruction) moved from MBR to IR
- MBR is now free for further data fetches

Fetch Sequence (symbolic)

(tx = time unit/clock cycle)

- t1: MAR ← PC
- t2: MBR ← (memory or MAR)
- t3: PC ← PC +1
  IR ← MBR

OR

- t1: MAR ← PC
- t2: MBR ← (memory or MAR)
  PC ← PC +1
- t3: IR ← MBR

Control Unit

The control unit is the heart of CPU. It gets instruction from memory. The control unit decides what the instructions mean and directs the necessary data to be moved from memory to ALU. It must communicate with both ALU and main memory. It coordinates all activities of processor unit, peripheral devices and storage devices. Two types of control unit can be implemented in computing systems.

1. **Hardwired Control Unit**

- This CU is essentially a combinatorial circuit. Its I/P logic signals are transformed into set of O/P logic signals which are control signals.
- The CU performs different operations in the basis of op-codes.
- We have to derive the Boolean expression for each control signal as a function of input.
- Since modern processor needs a Boolean equation, it is very difficult to build a combinational circuit that satisfies all these operations.

- It has faster mode of operation.
- A hardwired control unit needs rewiring if design has to be modified.

2. Micro-programmed Control Unit

- An alternative to hardwired CU.
- In micro-programmed control unit, the control information is stored in control memory.
- The control memory is programmed to initiate required sequence of operations.
- Use sequences of instructions to perform control operations performed by micro operations.
- Control address register contains the address of the next microinstruction to be read
- As it is read, it is transferred to control buffer register.
- Sequencing unit loads the control address register and issues a read command.
- It is cheaper and simple than hardwired CU.
- It is slower than hardwired CU.

1.8 Introduction to Register Transfer Language (RTL)

The symbolic notation used to describe the micro operation transfers among register is called register transfer language. It is one of the forms of hardware description language (HDL). The term 'register transfer' implies the availability of hardware logic circuits that can perform a stated instruction and transfer the data. It also transfers result of the operation to the same or another register. The term 'language' is borrowed from programmers, who apply this term to programming language.

RTL is the convenient tool for describing the internal organization of digital computers in concise and precise manner. It can also be used to facilitate the design process of digital systems such as microprocessors.

Fetch and execute cycle of MOV A, B in terms of RTL specification:

Within the fetch cycle, the operations performed during execution of instruction MOV A, B are:

i. The program counter contains the address of the next instruction to be executed. If the next instruction to be executed is MOV A, B; the program counter contains the address of the memory location where the instruction code for MOV A, B resides.
   In the first operation of fetch cycle, the contents of program counter will be transferred to the memory address register (MAR). The memory address register then uses the address bus to transmit its contents that specifies the address of memory location from where that instruction code of MOV A, B is to be fetched.
   Let t_1 indicates the period of first operation
   t_1: MAR $\leftarrow$ PC
ii. When the control unit issues the memory read signal, the contents o f the address memory location specified by MAR will be transferred to the memory buffer register (MBR).
   Suppose t_2 is the time period for this operation.
   t_2: MBR $\leftarrow$ Memory or [MAR]
iii. Finally the contents of MBR will be transferred to the instruction register and then the program counter gets incremented.
   Let t_3 be the time required by the CPU to complete these operations.
   t_3: IR $\leftarrow$ (MBR)

PC ← PC + 1

After the fetch cycle completed, the execution starts. The execute cycle steps:

i. At the start of execution cycle, the instruction register (IR) consists of instruction code for instruction MOV A, B. The address field of instructions specifies the addresses of the two memory locations A & B. The first step needed is to obtain the data from the location B. For this the address field of IR indicating the address of memory location will be transferred to address bus through the MAR. Let t_1 be the time taken during this operation.

   t_1: MAR ← (IR(Address of B))

ii. When the control unit issues a memory read signal, the contents of location B will be output (written) to the memory buffer register (MBR). Now the content of B which is to be written to memory location A is contained in MBR. Let t2 be the time taken for that operation.

   t_2: MBR ← (B)

iii. Now, we need the memory location of A because it is being written with the data of location B. For this the address field of IR indicating the address of memory location A. A will be transferred to MAR in time t3.

   t_3: MAR ← (IR(Address of A))

iv. When the control unit issues the memory write signal, the contents of MBR will be written to the memory location indicated by the contents of MAR in time t4.

   t_4: A ← MBR or t_4: [MAR] ← MBR

Program consists of instructions which contains different cycles like fetch and execute. These cycles in turn are made up of the smaller operation called micro operations.

Some RTL Examples

1) MVI A, 02H

   Fetch:

   T_1: MAR ← PC
   T_2: MBR ← [MAR]
   T_3: IR ← MBR, PC ← PC + 1
   T_4: Unspecified

   Execute:

   T_5: MAR ← PC
   T_6: MBR ← [MAR]
   T_7: A ← MBR, PC ← PC + 1

2) LXI B, C210H

   Fetch:

   T_1: MAR ← PC
   T_2: MBR ← [MAR]
   T_3: IR ← MBR, PC ← PC + 1
   T_4: Unspecified

Execute:

T_5: MAR ← PC
T_6: MBR ← [MAR]
T_7: C ← MBR, PC ← PC + 1

T_8: MAR ← PC
T_9: MBR ← [MAR]
T_{10}: C ← MBR, PC ← PC + 1

3) LDA 2030H

Fetch:

T_1: MAR ← PC
T_2: MBR ← [MAR]
T_3: IR ← MBR, PC ← PC + 1
T_4: Unspecified

Execute:

T_5: MAR ← PC
T_6: MBR ← [MAR]
T_7: Z ← MBR, PC ← PC + 1

T_8: MAR ← PC
T_9: MBR ← [MAR]
T_{10}: W ← MBR, PC ← PC + 1

T_{11}: MAR ← WZ
T_{12}: MBR ← [MAR]
T_{13}: A ← MBR

4) STAX D

Fetch:

T_1: MAR ← PC
T_2: MBR ← [MAR]
T_3: IR ← MBR, PC ← PC + 1
T_4: Unspecified

Execute:

T_5: MAR ← DE
T_6: MBR ← A
T_7: [MAR] ← MBR

5) ADD M

Fetch:

T_1: MAR ← PC
T_2: MBR ← [MAR]
T_3: IR ← MBR, PC ← PC + 1
T_4: Unspecified

Execute:

T_5: MAR ← HL
T_6: MBR ← [MAR]
T_7: TMP ← MBR

T_8: MAR ← PC
T_9: A ← A + TMP, MBR ← [MAR]
T_{10}: IR ← MBR, PC ← PC + 1

6) LHLD 4050H

Fetch:

T_1: MAR ← PC
T_2: MBR ← [MAR]
T_3: IR ← MBR, PC ← PC + 1
T_4: Unspecified

Execute:

T_5: MAR ← PC
T_6: MBR ← [MAR]
T_7: Z ← MBR, PC ← PC + 1

T_8: MAR ← PC
T_9: MBR ← [MAR]
T_{10}: W ← MBR, PC ← PC + 1

T_{11}: MAR ← WZ
T_{12}: MBR ← [MAR]
T_{13}: L ← MBR

T_{14}: MAR ← WZ + 1
T_{15}: MBR ← [MAR]
T_{16}: H ← MBR

Advantages of Microprocessor:

- Computational/Processing speed is high
- Intelligence has been brought to systems
- Automation of industrial process and office automation
- Flexible
- Compact in size
- Maintenance is easier

Applications of Microprocessors:

- Microcomputer:- Microprocessor is the CPU of the microcomputer.
- Embedded system:- Used in microcontrollers.
- Measurements and testing equipment:- Used in signal generators, oscilloscopes, counters, digital voltmeters, x-ray analyzer, blood group analyzers baby incubator, frequency synthesizers, data acquisition systems, spectrum analyzers etc.
- Scientific and Engineering research.
- Industry:- Used in data monitoring system, automatic weighting, batching systems etc.
- Security systems:- Smart cameras, CCTV, smart doors etc.
- Automatic system
- Communication system

  Some Examples are:
  - Calculators
  - Accounting system
  - Games machine
  - Complex Industrial Controllers
  - Traffic light Control
  - Data acquisition systems
  - Military applications