Introduction to microprocessor

Introduction

The microprocessor is a programmable integrated device that as computing and decision-making capability similar to that of the central processing unit (CPU) of a computer. It can be an embedded in a larger system, can be a stand-alone unit controlling processes, or it can function as the CPU of a computer called microcomputer.

It 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.

A typical programmable machine can be represented with four components: microprocessor, memory, input, and output. These four components work together or interact with each other to perform a given task; thus, they comprise a system. The physical components of this system are called hardware. A set of instruction written for the microprocessor to perform a task is called a program, and a group of programs is called software.

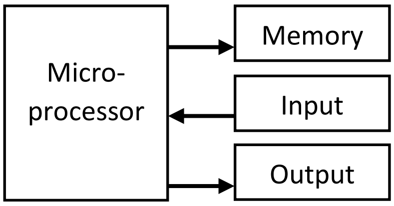


Figure 1 A programmable machine

Architecture of microprocessor-based system

Based on the way the CPU access the memory, there are two types of architecture:

1. Von Neumann
2. Harvard

1. Von Neumann architecture

The Von Neumann architecture is also known as Princeton architecture was proposed by John Von Neumann in the year 1945 and it is an architecture where the data and programs are subjected to shared memory i.e., are stored in the same memory block.

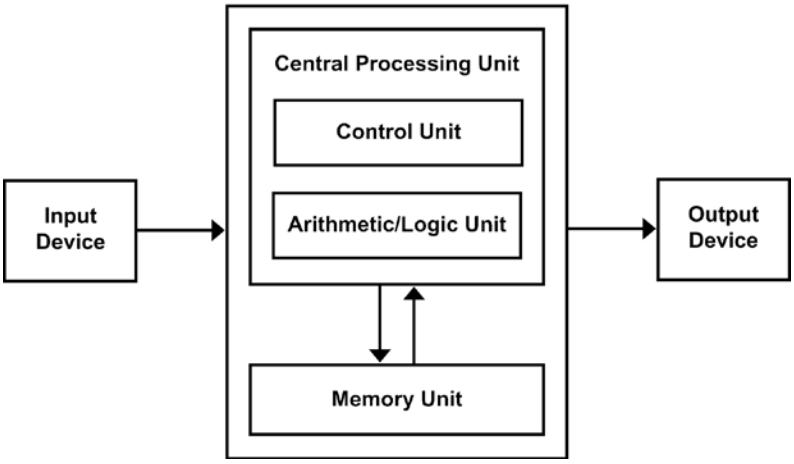


Figure 2 Von Neumann Architecture

2. Harvard Architecture

A computer architecture where the memory unit is divided into two parts for individually storing data and instructions is known as Harvard architecture. This means, unlike Von Neumann architecture, here data memory and instruction memory is in separate format.

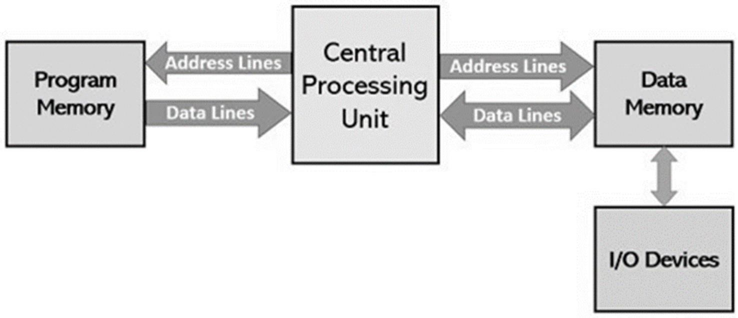


Figure 3 Harvard Architecture

Comparison of Von Neumann and Harvard architecture

BASIS FOR COMPARISON	VON NEUMANN ARCHITECTURE	HARVARD ARCHITECTURE
BASIC	Data and instructions reside within a single memory unit.	Data and instruction are provided 2 different memory units.
BASED ON	Stored program computer concept	Harvard Mark I relay based model
MEMORY SYSTEM	Single	Dual
REQUIRED SPACE	Less	Comparatively more
SET OF ADDRESS/ DATA BUS	One	Two
DEVELOPMENT COST	Low	Comparatively more
EFFICIENCY	Less	More
EXECUTION SPEED	Slow	Comparatively fast
OPERATION	Simple	Complex
PERFORMANCE OFFERED	Low	Comparatively high
CLOCK CYCLE	Single instruction is executed in minimum two clock cycles.	Single instruction is executed in one clock cycle.
FEATURE	Data transfer and instruction fetching do not occur simultaneously.	Data transfer and instruction fetch take place at the same time.
SPACE UTILIZATION	Good	Not so good
APPLICATIONS	PCs, workstations, notebooks, etc.	Microcontrollers, digital signal processing, etc.

Evolution of Microprocessors

4 bit Microprocessors

4004

- Introduced in 1971
- First microprocessor by Intel
- It was a 4-bit microprocessor
- Its clock speed was 740 KHz
- It had 2,300 transistors
- It could execute around 60,000 instructions per seconds
- Used in calculators

4040

- Introduced in 1974
- 4-bit microprocessor
- 3,000 transistors were used
- Clock speed was 740 KHz
- Interrupt features were available

8 Bit Microprocessors

8008

- Introduced in 1972 it was first 8 bit microprocessor
- Its clock speed was 500 KHz
- Could execute 50,000 instruction per second
- Used in: Computer terminals, Calculator, Bottling Machines, industrial Robots

8080

- Introduced in 1974
- It was also 8-bit microprocessor
- Its clock speed was 2 MHz
- It has 6,000 transistors
- 10 times faster than 8008
- Could execute 500,000 instructions per second
- Used In: Calculators, Industrial Robots

8085

- Introduced in 1976
- It was also 8-bit microprocessor
- Its clock speed was 3 MHz
- Its data bus is 8 bit and address bus is 16 bit
- It has 6,500 transistors
- It could execute 769,230 instructions per second
- It could access 64KB of memory
- It has 246 instructions
- Used In: early PC, On-Board Instrument Data Processors

16 Bit Microprocessors

8086

- Introduced in 1978
- First 16-bit microprocessor
- Clock speed is 5 to 10 MHz
- Data bus is 16-bit and address bus is 20-bit
- It had 29,000 transistors
- It could execute 2.5 million instructions per second
- Could access 1MB of memory
- It had 22,000 instructions
- Used In: CPU of Microcomputers

8088

- Introduced in 1979
- It was also 16-bit microprocessor
- It was creates as cheaper version of Intel's 8086
- 16-bit processor with an 8-bit data bus
- Could execute 2.5 million instructions per second
- The chip become the most popular in the computer industry when IBM used it for its first PC

80286

- Introduced in 1982
- It was 16-bit microprocessor
- Its clock speed was 8 MHz
- Data bus is 16-bit and address bus is 24-bit
- Could address 16 MB of memory
- It has 134,000 transistors
- Could execute 4-million instructions per second

32 Bit Microprocessors

80386

- Introduced in 1986
- First 32-bit microprocessor
- Data bus is 32 bit and address bus is 32-bit
- It could address 4GB of memory
- It has 275,000 transistors
- Clock speed varied from 16 MHz to 33 MHz depending upon different versions
- Different Versions
  - 80386DX
  - 80386SX
  - 80386SL

80486

- Introduced in 1989
- 32-bit microprocessor
- Had 1.2 million transistors

- Clock speed varied from 16 MHz to 100 MHz depending upon the various versions
- It had five different versions
  - 80486DX
  - 80486SX
  - 80486DX2
  - 80486SL
  - 80486DX4
- 8KB of cache memory was introduced

Pentium

- Introduced in 1993
- It was also 32-bit microprocessor
- Clock speed was 66 MHz
- Data bus is 32-bit and address bus is 32-bit
- Could address 4GB of memory
- Could execute 110 million instructions per second
- Cache memory
  - 8KB for Instruction
  - 8KB for data
- Upgraded Version: Pentium Pro

Pentium II

- Introduced in 1997
- 32-bit microprocessor
- Clock speed was 233 to 450 MHz
- MMX technology was supported
- L2 cache and processor were on one circuit
- Upgraded Version: Pentium II Xenon

Pentium III

- Introduced in 1999
- It was 32-bit microprocessor
- Clock speed varied from 500 MHz to 1.4 GHz
- It had 9.5 million transistors

Pentium IV

- Introduced in 2000
- 32-bit microprocessor
- Clock speed was from 1.3 GHz to 3.8 GHz
- L1 cache was 32 KB and L2 cache was 256 KB
- It had 42 million transistors

Intel Dual Core

- Introduced in 2006
- It is 32-bit or 64-bit Microprocessor
- It has 2-cores
- Both cores have their own internal bus and L1 cache but share the external bus and L2 cache

- Support SMT (Simultaneously Multithreading Technology)

64 Bit Microprocessors

Intel Core 2

- Introduced in 2006
- 64-bit microprocessor
- Clock speed is from 1.2 GHz to 3GHz
- It has 291 million transistors
- L1 cache- 64 KB per core
- L2 cache- 4 MB
- Versions:
    - Intel Core 2 Duo
    - Intel Core 2 Quad
    - Intel Core 2 Extreme

Intel Core i7

- Introduced in 2008
- 64-bit microprocessor
- It has 4 physical cores
- Clock speed is from 2.67 GHz to 3.33 GHz
- It has 781 million transistors
- L1 cache- 32 KB per core
- L2 cache- 256 KB
- L3 cache- 8 MB

Intel Core i5

- Introduced in 2009
- It is a 64-bit microprocessor
- It has 4 physical cores
- Its clock speed is from 2.40 GHz to 2.8 GHz
- It has 781 million transistors
- L1 cache- 32 KB per core
- L2 cache- 256 KB
- L3 cache- 8 MB

Intel Core i3

- Introduced in 2010
- 64-bit microprocessor
- It has 2 physical cores
- Clock speed is from 2.93 GHz to 3.33 GHz
- It has 781 million transistors
- L1 cache- 32 KB per core
- L2 cache- 256 KB
- L3 cache- 4 MB

MICROPROCESSORS, MICROCOMPUTERS, AND ASSEMBLY LANGUAGE

Intel Microprocessors: Historical Perspective

Processor	Year of Introduction	Number of Transistors	Initial Clock Speed	Address Bus	Data Bus	Addressable Memory
4004	1971	2,300	108 kHz	10-bit	4-bit	640 bytes
8008	1972	3,500	200 kHz	14-bit	8-bit	16 K
8080	1974	6,000	2 MHz	16-bit	8-bit	64 K
8085	1976	6,500	5 MHz	16-bit	8-bit	64 K
8086	1978	29,000	5 MHz	20-bit	16-bit	1 M
8088	1979	29,000	5 MHz	20-bit	8-bit*	1 M
80286	1982	134,000	8 MHz	24-bit	16-bit	16 M
80386	1985	275,000	16 MHz	32-bit	32-bit	4 G
80486	1989	1.2 M	25 MHz	32-bit	32-bit	4 G
Pentium	1993	3.1 M	60 MHz	32-bit	32/64-bit	4 G
Pentium Pro	1995	5.5 M	150 MHz	36-bit	32/64-bit	64 G
Pentium II	1997	8.8 M	233 MHz	36-bit	64-bit	64 G
Pentium III	1999	9.5 M	650 MHz	36-bit	64-bit	64 G
Pentium 4	2000	42 M	1.4 GHz	36-bit	64-bit	64 G

*External 8-bit and internal 16-bit data bus

Microcomputer

The term microcomputer is generally synonymous with personal computer, or a computer that depends on a microprocessor. Microcomputers are designed to be used by individuals, whether in the form of PCs, workstations or notebook computers. A microcomputer contains a CPU on a microchip (the microprocessor), a memory system (typically ROM and RAM), a bus system and I/O ports, typically housed in a motherboard.

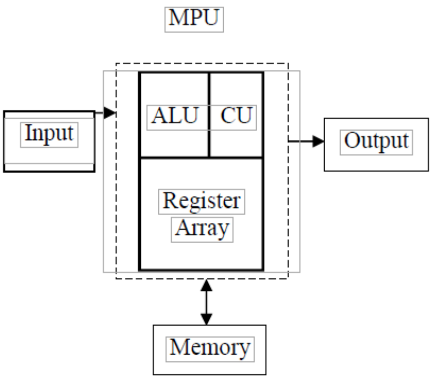
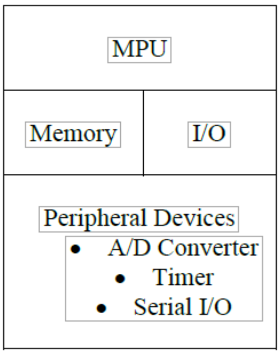
Microcomputers are small computers. They range from small controllers that work directly with 4-bit words to larger units that work directly with 32-bit words. Some of the more powerful Microcomputers have all or most of the features of earlier minicomputers. Examples of Microcomputers are Intel 8051 controller-a single board computer, IBM PC and Apple Macintosh computer.

Microcontroller

It is a highly integrated chip that contains all the components comprising a controller. Single-chip Microcomputers are also known as Microcontrollers. They are used primarily to perform dedicated functions.

Generally, they include all the essential elements of a computer on a single chip: MPU, R/W memory, ROM and I/O lines and timers. Unlike a general-purpose computer, which also includes all of these components, a microcontroller is designed for a very specific task - to control a particular system. A microcontroller differs from a microprocessor, which is a general-purpose chip that is used to create a multi-function computer or device and requires multiple chips to handle various tasks. A microcontroller is meant to be more self-contained and independent, and functions as a tiny, dedicated computer. The great advantage of microcontrollers, as opposed to using larger microprocessors, is that the parts-count and design costs of the item being controlled can be kept to a minimum. Some examples of the microcontrollers are Intel 8051, PIC, ARM, and AVR.

Difference between Microprocessors and Microcontrollers

Microprocessors	**Microcontrollers**
1. Microprocessor is a silicon chip which includes ALU, register circuit and control circuits.	1. Microcontroller is a silicon chip which includes microprocessor, memory and I/O in a single package.
2. Normally used for general purpose computers as CPU.	2. Normally microcontrollers are used for specific purposes (embedded system) e.g. traffic light controller, printer, etc.
3. The performance speed, i.e. clock speed of microprocessor is higher.	3. The performance speed of microcontroller is relatively slower than that of microprocessors.
4. Addition of external RAM, ROM and I/O ports makes these systems bulkier and much more expensive.	4. Has fixed memory and all peripherals are embedded together on a single chip, so are not bulkier and are cheaper than microprocessors.
5. Microprocessors are more versatile than microcontrollers as the designers can decide on the amount of RAM, ROM and I/O ports needed to fit the task at hand.	5. As microcontrollers have already fixed amount of RAM, ROM and I/O ports, so are not versatile as the user cannot change the amount of memory and I/O ports.
6. The general block diagram to show microprocessor is as shown 	6. The general block diagram of microcontroller is as shown 

8085 microprocessor

The 8085 is an 8-bit microprocessor. It was launched by the Intel team in the year of 1976. The configurations of 8085 microprocessor includes 8-bit data bus, 16 bit address bus, 16-bit program counter, 16 bit stack pointer, 8-bit registers, +5V voltage supply, and operates at 3.2 MHz single segment CLK. The applications of 8085 microprocessor are involved in microwave ovens, washing machines, gadgets, etc. The features of the 8085 microprocessor are as below:

- The processor consists of 16-bit address lines, so the capacity of the device is 2^{16} which is 64KB of memory.
- This is constructed of a single NMOS chip device and has 6200 transistors
- A total of 246 operational codes and 80 instructions are present

- As the 8085 microprocessor has 8-bit input/output address lines, it has the ability to address 2^8 = 256 input and output ports.
- This microprocessor is available in a DIP package of 40 pins
- It has an internal clock generator
- It functions on a clock cycle having a duty cycle of 50%

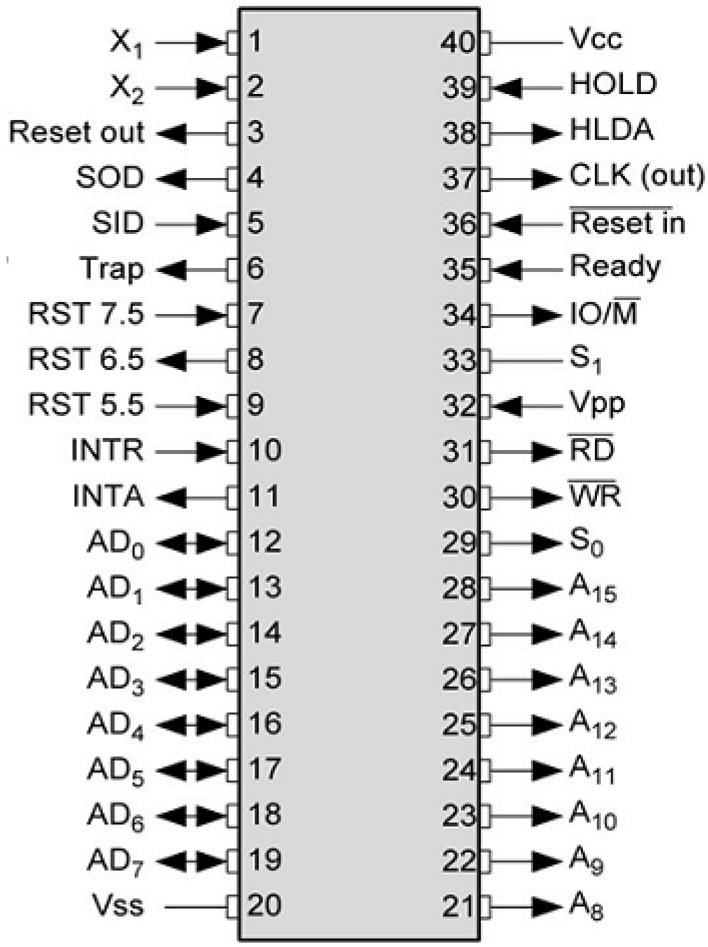


Figure 4 Pin diagram of 8085

- **AD0-AD7**: Multiplexed Address and data lines.
- **A8-A15**: Tri-stated higher order address lines.
- **ALE**: Address latch enable is an output signal. Making ALE control HIGH the multiplexed 8 bit bus will act as address bus while making ALE control LOW the same 8 bit multiplexed bus will act as data bus. Thus, ALE = 1 makes the address latched i.e. latch enable and ALE = 0 makes the address bus disable but making it data bus enable. In this sense, this 8 bit bus better should be said as data bus.
- **S0, S1**: These are the status signals used to indicate type of operation.
- **$\overline{\text{RD}}$:** Read is active low input signal used to read data from I/O device or memory.
- **$\overline{\text{WR}}$**: Write is an active low output signal used write data on memory or an I/O device.
- **READY**: This an output signal used to check the status of output device. If it is low, microprocessor will WAIT until it is high.
- **TRAP**: It is an Edge triggered highest priority, non-maskable interrupt. After TRAP, restart occurs and execution starts from address 0024H.
- **RST 5.5, 6.5, 7.5**: These are maskable interrupts and have low priority than TRAP.

- **INTR & $\overline{\text{INTA}}$**: INTR is an interrupt request signal after which microprocessor generates INTA or interrupt acknowledge signal.
- **IO/$\overline{\text{M}}$**: This is output pin or signal used to indicate whether 8085 is working in I/O mode (IO/M=1) or Memory mode (IO/M=0).
- **HOLD & HLDA**: HOLD is an input signal. When microprocessor receives HOLD signal it completes current machine cycle and stops executing next instruction. In response to HOLD microprocessor generates HLDA that is HOLD Acknowledge signal.
- **$\overline{\text{RESETIN}}$**: This is input signal. When RESETIN is low microprocessor restarts and starts executing from location 0000H.
- **SID**: Serial input data is input pin used to accept serial 1 bit data.
- **SOD**: Serial output data is output pin used to send serial 1 bit data.
- **X1, X2**: These are clock input signals and are connected to external LC or RC circuit. These are divided by two so if 6 MHz is connected to X1 X2, the operating frequency becomes 3 MHz.
- **VCC & VSS**: Power supply VCC=+ -5 Volt & VSS=-GND reference.

Internal architecture of 8-bit microprocessor 8085

8085 microprocessor is an 8-bit parallel central processing unit (CPU). The internal architecture of the 8085 microprocessor consists of an array of registers, encoder/decoder, arithmetic logic unit, and timing and control circuits. An internal data bus links all of these components inside the processor.

The block diagram below shows the internal architecture of the 8085 microprocessors.

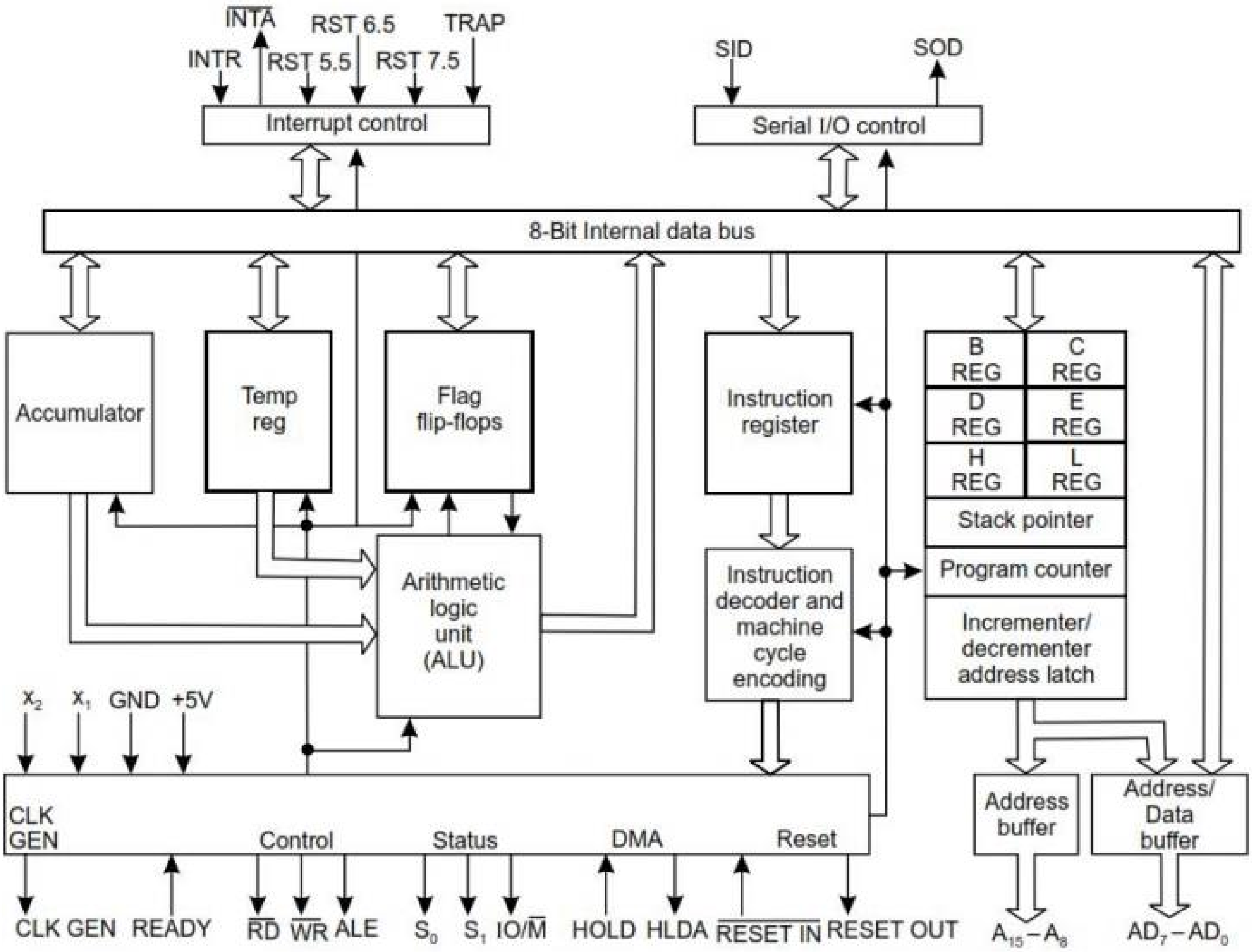


Figure 5 Architecture of 8085

Arithmetic and Logic Unit (ALU):

It is used to perform mathematical operations like: addition, multiplication, subtraction, division, decrement, increment, etc.

Flag Register:

It is an 8-bit register having five 1-bit flip-flops, which holds either 0 or 1 depending upon the result stored in the accumulator.

These are the set of 5 flip-flops –

- Sign (S)
- Zero (Z)
- Auxiliary Carry (AC)
- Parity (P)
- Carry (C)

Its bit position is shown in the following table –

D7	D6	D5	D4	D3	D2	D1	D0
S	Z		AC		P		C

1) **The carry flag (CF):** This flag is set whenever there has been a carry out of, or a borrow into, the higher order bit of the result. The flag is used by the instructions that add amd subtract multibyte numbers.
   - 1-carry out from MSB bit on addition or borrow into MSB bit on subtraction
   - 0-no carry out or borrow into MSB bit
2) **The parity flag (PF):** This flag is set whenever the result has even parity, an even number of 1 bits. If parity is odd, PF is cleared.
   - 1-low byte has even number of 1 bits
   - 0-low byte has odd parity
3) **The auxiliary carry flag (AF):** This flag is set whenever there has been a carry out of the lower nibble into the higher nibble or a borrow from higher nibble into the lower nibble of an 8 bit quantity, else AF is reset. This flag is used by decimal arithmetic instructions.
   - 1-carry out from bit 3 on addition or borrow into bit 3 on subtraction
   - 0-otherwise
4) **The zero flag (ZF):** This flag is set, when the result of operation is zero, else it is reset.
   - 1-zero result
   - 0-non-zero result
5) **The sign flag (SF):** This flag is set, when MSB (Most Significant Bit) of the result is 1. Since negative binary numbers are represented in the 8085 CPU in standard two's complement notation, SF indicates sign of the result.
   - 1-MSB is 1 (negative)
   - 0-MSB is 0 (positive)

Accumulator:
Accumulator is used to perform I/O, arithmetic and logical operations. It is connected to ALU and internal data bus.

General Purpose Registers:
There are 6 general purpose registers. These registers can hold 8-bit values. These 8-bit registers are B, C, D, E, H, L. These registers work as 16-bit registers when they work in pair like: B-C, D-E, H-L.

Program Counter:
Program Counter holds the address value of the memory to the next instruction that is to be executed. It is a 16-bit register.

Stack Pointer:
It works like stack. In stack, the content of register is stored that is later used in the program. It is a 16-bit special register.

Temporary Register:
It is an 8-bit register that holds data values during arithmetic and logical operations.

Instruction register and decoder:
It is an 8-bit register that holds the instruction code that is being decoded. The instruction is fetched from the memory.

Timing and control unit:
The timing and control unit comes under the CPU section, and it controls the flow of data from CPU to other devices. It is also used to control the operations performed by the microprocessor and the devices connected to it. There are certain timing and control signals like: Control signals, DMA Signals, RESET signals, Status Signal.

READY: This pin is used to specify whether the peripheral is able to transfer information or not. When this pin is high, it transfers data and if this is low, the microprocessor device needs to wait until the pin goes to a high state.

Control signal

RD: This is the signal used for the regulation of READ operation. When the pin moves into low, it signifies that the chosen memory is read.

WR: This is the signal used for the regulation of WRITE operation. When the pin moves into low, it signifies that the data bus information is written to the chosen memory location.

ALE: ALE corresponds to Address Latch Enable signal. The ALE signal is high at the time of the machine's initial clock cycle and this enables the last 8 bits of the address to get latched with the memory or external latch.

Status signal

IO/M: This signal is used to differentiate between IO and Memory operations, i.e. when it is high indicates IO operation and when it is low then it indicates memory operation.

S1 & S0: These are status signals. They distinguish the various types of operations such as:

S0	S1	Functionality
0	0	Halt
1	0	Write
0	1	Read
1	1	Fetch

DMA signal

DMA is a process of communication for data transfer between memory and input/output, controlled by an external circuit called DMA controller, without involvement of CPU.

8085 MP has two pins HOLD and HLDA which are used for DMA operation.

- HLDA: This is the signal for HOLD acknowledgment that signifies the received signal of HOLD request. When the request is removed, the pin goes to a low state. This is the output pin.
- HOLD: This pin indicates that the other device is in the need to utilize data and address buses. This is the input pin.

First, DMA controller sends a request by making Bus Request (BR) control line high. When MP receives high signal to HOLD pin, it first completes the execution of current machine cycle, it takes few clocks and sends HLDA signal to the DMA controller.

After receiving HLDA through Bus Grant (BG) pin of DMA controller, the DMA controller takes control over system bus and transfers data directly between memory and I/O without involvement of CPU. During DMA operation, the processor is free to perform next job which does not need system bus.

At the end of data transfer, the DMA controller terminates the request by sending low signal to HOLD pin and MP regains control of system bus by making HLDA low.

Reset Signals

There are two reset pins which are Reset In and Reset Out at pins 3 and 36.

RESET IN: This pin signifies resetting the program counter to zero. Also, this pin resets the HLDA flip-flops and IE pins. The control processing unit will be in a reset state till RESET is not triggered.

RESET OUT: This pin signifies that the CPU is in reset condition.

Interrupt control:

Whenever a microprocessor is executing a main program and if suddenly an interrupt occurs, the microprocessor shifts the control from the main program to process the incoming request. After the request is completed, the control goes back to the main program. There are 5 interrupt signals in 8085 microprocessors: INTR, TRAP, RST 7.5, RST 6.5, RST 5.5

Interrupt Signal	**Next instruction location**
TRAP	0024
RST 7.5	003C
RST 6.5	0034
RST 5.5	002C

The priority list of these interrupt signals is

- TRAP – Highest
- RST 7.5 – High
- RST 6.5 – Medium
- RST 5.5 – Low
- INTR – Lowest

INTA: This pin is the interrupt acknowledgment that is directed by the microprocessor device after the receival of the INTR pin. This is the output pin.

Address buffer and address-data buffer

The content stored in the stack pointer and program counter is loaded into the address buffer and address-data buffer to communicate with the CPU. The memory and I/O chips are connected to these buses; the CPU can exchange the desired data with the memory and I/O chips.

Address bus and data bus

Data bus carries the data to be stored. It is bidirectional, whereas address bus carries the location to where it should be stored and it is unidirectional. It is used to transfer the data & Address I/O devices.

Serial Input/output control:

It controls the serial data communication by using these two instructions: SID (Serial input data) and SOD (Serial output data).

Clock signals

There are 3 clock signals, i.e. X1, X2, CLK OUT.

X1, X2 – A crystal (RC, LC N/W) is connected at these two pins and is used to set frequency of the internal clock generator. This frequency is internally divided by 2.

CLK OUT – This signal is used as the system clock for devices connected with the microprocessor.

Instruction cycle

The instruction cycle (also known as the fetch–decode–execute cycle) is the cycle that the central processing unit (CPU) follows to process the instructions. It has three main stages: the fetch stage, the decode stage, and the execute stage.

1. Fetch Stage: The next instruction is fetched from the memory address that is currently stored in the program counter and stored into the instruction register (Gets an instruction from memory). At the end of the fetch operation, the PC points to the next instruction that will be read at the next cycle.
2. Decode Stage: During this stage, the encoded instruction presented in the instruction register is interpreted by the decoder. (Decides what the instruction means)
3. Execute Stage: The control unit of the CPU passes the decoded information as a sequence of control signals to the relevant functional units of the CPU to perform the actions required by the instruction, such as reading values from registers, passing them to the ALU to perform mathematical or logic functions on them, and writing the result back to a register. (Performs the instruction)