Digital Computer:

A computer is a multipurpose programmable machine that reads binary instructions from its memory, accepts binary data as input, processes the data according to those instructions and provides results as output. It is a programmable device made up of both *hardware* and *software*.

The various components of the computer are called *hardware*. A set of instructions written for the computer to solve a specific task is called program and collection of programs is called *software.*

The computer hardware consists of four main components.

a. Central processing unit acts as computer‘s brain.
b. Memory in which data and programs are stored.
c. Input unit through which program and data can be entered to computer
d. Output unit on which the results of the computations can be displayed.

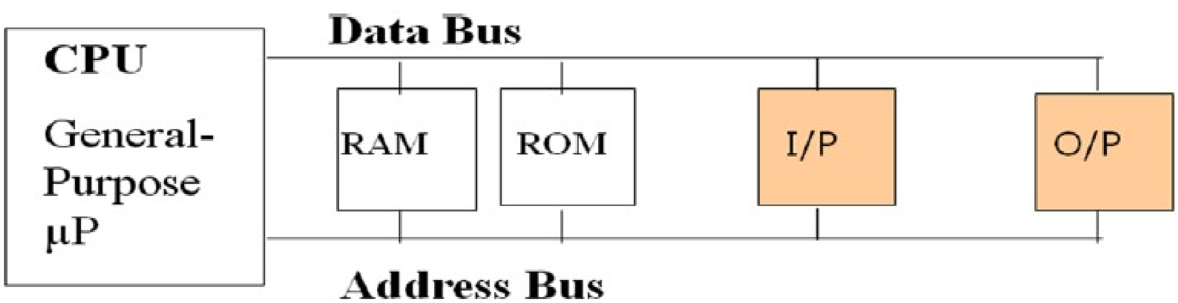


Fig 1.1 Block diagram of a microcomputer

A computer that is designed using a microprocessor as its CPU, is known as a microcomputer. Microprocessor first became a commercial reality in 1971 with the introduction of the 4 bit 4004 by Intel. A byproduct of Microprocessor development was Microcontroller. The same fabrication technology and programming concept that make the general purpose microprocessor also yielded the Microcontroller.

Microprocessors:

- A microprocessor is a multipurpose programmable device that can process data.
- Block diagram of a Microprocessor CPU which contains ALU; Program counter (PC), a stack pointer (SP), some working registers, clock timing circuit and interrupt circuit is shown in the following figure 1.2.

- To make a microcomputer one must add memory usually RAM and ROM, memory decoders, an oscillator and a number of Input, Output devices such as serial and parallel ports.
- In addition special purpose devices such as interrupt handler and counters may be added to relieve the CPU from time consuming counting or timing cores.
- When the microcomputer is equipped with mass storage devices, I/O peripherals such as a key board and a display CRT it yields a small computer that can be applied to a range of general purpose applications.

- The hardware design of a microprocessor is arranged such that a very small or very large system can be configured around the CPU as the application demands as shown in Fig1.1.
- The prime use of the Microprocessor is to read data, perform extensive calculations on that data, and store those calculations in a mass storage device or display the results for human use.
- The programs used by microprocessor are stored in the mass storage device and loaded into RAM as user directs. A few microprocessor program are stored in ROM. The ROM based programs are primarily small fixed programs that operate peripherals and other fixed devices that are connected to the system.

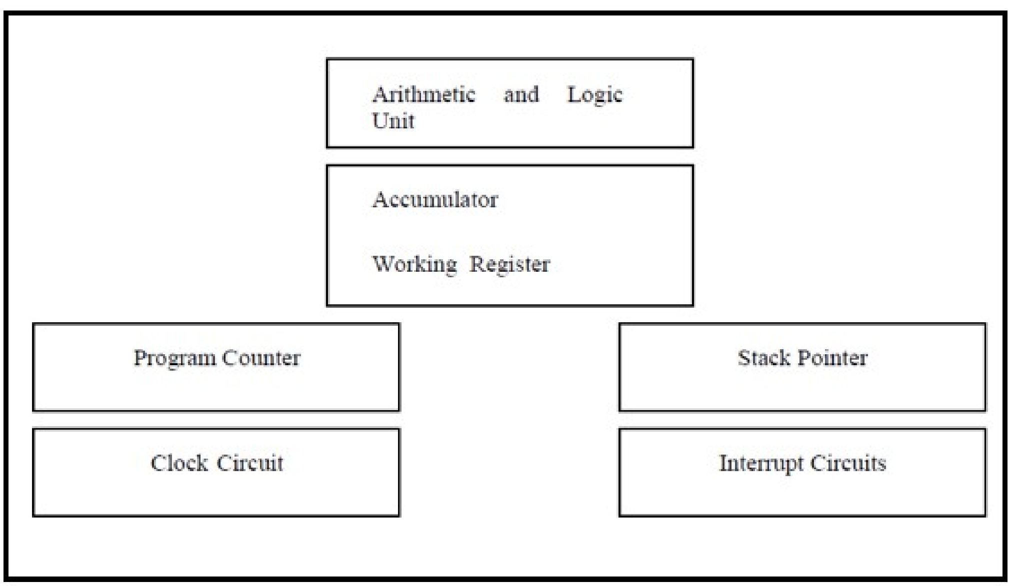


Fig 1.2 Block diagram of CPU of a microprocessor

Microcontroller:

- The microcontroller incorporates all the features that are found in microprocessor.
- The microcontroller has built in ROM, RAM, Input Output ports, Serial Port, timers, interrupts and clock circuit. A microcontroller is an entire computer manufactured on a single chip.
- Microcontrollers are usually dedicated devices embedded within an application. For example, microcontrollers are used as engine controllers in automobiles and as exposure and focus controllers in cameras.
- In order to serve these applications, they have a high concentration of on-chip facilities such as serial ports, parallel input output ports, timers, counters, interrupt control, analog-to-digital converters, random access memory, read only memory, etc.
- The I/O, memory, and on-chip peripherals of a microcontroller are selected depending on the specifics of the target application.
- Since microcontrollers are powerful digital processors, the degree of control and programmability they provide significantly enhances the effectiveness of the application.
- The 8051 is the first microcontroller of the MCS-51 family introduced by Intel Corporation at the end of the 1970s.
- Microcontroller can be classified on the basis of their bits processed like 8bit MC, 16bit MC.8 bit microcontroller, means it can read, write and process 8 bit data. Ex. 8051 microcontroller. Basically 8 bit specifies the size of data bus. 8 bit microcontroller means 8 bit data can travel on the data bus or we can read, write process 8 bit data.
- Applications:widely used in washing machines, vcd player, microwave oven, robotics or in industries.

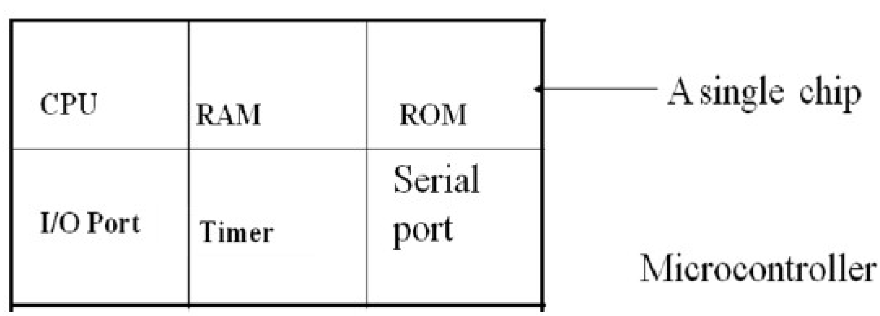
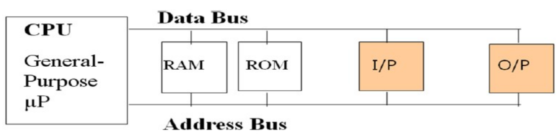
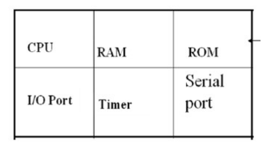


Fig1.3 Block diagram of a microcontroller

Comparison of Microprocessors and microcontrollers:

Microprocessor	Microcontroller
	
Contains only CPU. ROM,RAM,I/O, timer are separately interfaced	CPU, ROM,RAM,I/O and timer are all on a single chip
Designer decides on the amount of ROM, RAM and I/O ports	Fixed amount of ROM, RAM and I/0 ports
High cost	Low cost
Versatile and General purpose	Single purpose and not very versatile
High power consumption	Low power consumption
Large number of instructions with flexible addressing modes.	Limited number of instructions with few addressing modes
Very few bit manipulation instructions	Many bit manipulation instructions
MP based system requires more hardware	MC based system requires less hardware
MPs have less number of registers. So more operations are memory based.	MPs have more number of registers. So more operations are register based.
Based on Von Neumann architecture where programs and data are store in same memory module.	Based on Harvard architecture, where program memory and data memory are separate.
Used in personal computers, laptops,	Used mainly in appliances such as washing machines, ovens etc.

CISC and RISC systems:

Based on the instruction set, we broadly classify computers/ microprocessors/ microcontrollers into CISC (Complex Instruction Set Computers) and RISC(Reduced instruction Set Computers) devices.

In CISC devices there are a large number of instructions, each of which has a different permutation of the same operation (like data access, data transfer etc.). This gives the programmer flexibility in writing the programs. The major characteristics of CISC systems are:

- Typically large number of instructions; around 100-250 instructions

- Some instructions perform specialized tasks and are used infrequently
- A large number of addressing modes
- Variable length instruction formats
- Execution time for an instruction may take several clock cycles
- Execution time for each instruction may be different
- Efficient use of memory
- Robustness of instruction set is given precedence over speed
- Instructions are available to manipulate operands in memory
- Eg: 8085,8086, Pentium(all From Intel), M6800(Motorola), Z-80(Zilog) and microcontrollers of 8051 series(Intel)

RISC processors have very limited number of instructions. The major characteristics of RISC systems are:

- Relatively few instructions
- Instructions are executed in small clock periods and hence they are faster than CISC
- Very few addressing modes
- Limited memory access made available to certain instructions
- All operations are performed within the registers of CPU
- Instructions are of fixed length
- Control is hardwired in the system
- Eg: PIC microcontroller series from Microchip(Only 33/35 instructions)

CPU Architecture (Von Neumann and Harvard Architecture):

Every computer needs to store the instructions or code and also the data. Depending on how these are stored in memory and how the memory is accessed we have two broad classifications for the architecture namely Harvard and Von Neumann. The fig 1.4 shows the two architectures.

The main features of **Von Neumann Architecture** are:

- It uses a single memory space for both instructions and data. It is also called a 'stored program computer'.
- It has limited data transfer rate called throughput between the CPU and the memory, compared to the amount of memory. Since the CPU processing speed is much higher, the CPU has to wait for vital data to be transferred to or from memory.
- Program modifications can be harmful either by accident or design.
- One bus is used to carry the address and data with an appropriate multiplexing technique, which in turn reduces the cost.

- Eg: 8085, 8086, M6800

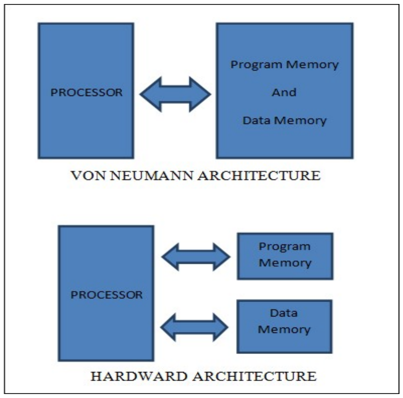


Fig 1.4 Von Neumann and Harvard architecture

The main characteristics of**Harvard architecture** are:

- Physically separate storage and signal pathways for instructions and data. This implies that there is separate 'Program memory' and 'data memory'.
- The characteristics of the two memories like the word width, timing implementation technology, and memory address structure and size can be different.
- Separate address and data bus for each Program and Data memory
- Since there are separate bus for access the operation of fetching the code and data can happen simultaneously which increases the speed of operation of execution inside CPU.
- Harvard architecture are frequently used in specialized digital signal processors (DSPs), commonly used in audio or video processing products.
- Eg: PIC microcontrollers by Microchip technologies, AVR by Atmel Corp.

Computer Software:

A set of instructions written in a specific sequence for computer to solve a specific task is called a program, and software is collection of programs. The program stored in the computer memory in the form of 0s and 1sand it is called as machine level instructions. Since it would be difficult to remember machine codes in the form of binary numbers an intermediate level of language for programming, between higher and machine level was developed and is known as assembly level language. Assembly language programs are written using assembly instructions known as mnemonics.

For example in CLR A, instruction CLR means clear and A means accumulator. The program mnemonics are converted to machine codes in the form of binary by a software called *Assembler.*

The Assembly language programming requires a detailed knowledge of the architecture with which the program is executed. In order to overcome the drawback of assembly language programming. Higher level language like C, C++ are introduced where an interpreter or a compiler takes care of translating a higher level source code into machine codes.

8051 Architecture:

The block diagram of 8051 is shown in figure 1.5.

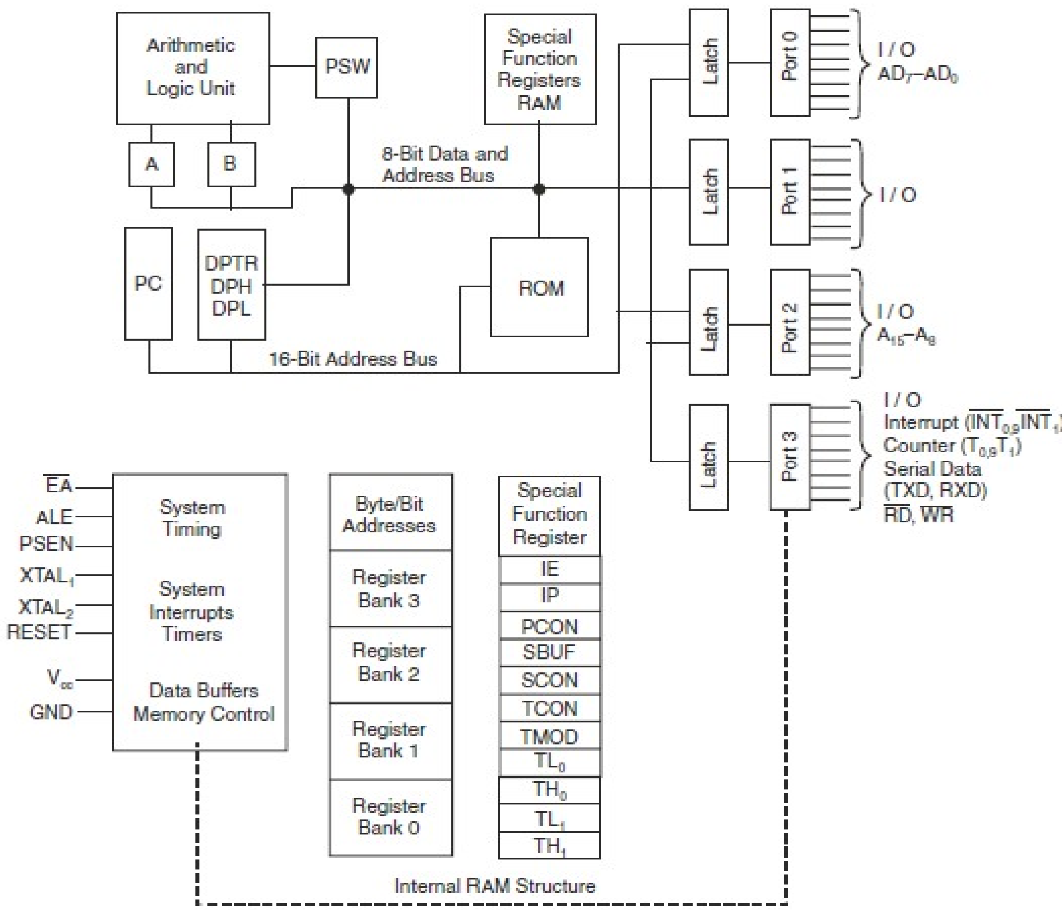


Fig 1.5 Block diagram of 8051

Features of 8051:

- ALU(arithmetic and Logical Unit) is used for arithmetic calculations.
- Eight bit CPU with registers A (Accumulator) and B. Accumulator is used for arithmetic and logic operations. A register holds the first operand and also gets the result of the operation.Also it is the only register to be used for data transfers to and from external memory. Register B is used for integer multiplication and division.

- 16 bit Program counter (PC) holds the address of the location of the next instruction to be executed. It is 16 bit register means the 8051 can access program address from 0000H to FFFFH. It gets automatically incremented as soon as any instruction is fetched,
- 16 bit Data pointer (DPTR) is used to access external memory. It is divided into two parts DPH and DPL. DPH for Higher order 8 bits, DPL for lower order 8 bits. It is typically used by the programmer to transfer data from external memory. It is also used a pointer to a look up table in external ROM using indexed addressing mode.
- 8 Bit Program Status Word (PSW) indicates certain conditions like status of carry, parity, sign etc. after execution of some instructions. It is abit addressable register.
- Stack Pointer(SP): It is an 8-bit register. It contains address of top of the stack. The stack is present in the internal RAM.
- 4K Internal Code Memory (ROM). It is used to store programs. Hence also called as program memory or code memory.It may also contain some permanent data stored in the form of lookup table.
- Internal Memory of 128 Bytes divided as:
    - 4 register banks of 8 registers each
    - 16 bytes, which are bit addressable. The individual bits of these bytes can be altered
    - 80 bytes of general RAM memory
- 32 I/O Pins arranged as four 8 Bit ports (P0-P3) for data exchange with the external device.
- Two 16 Bit Timer/Counter: Timer0, Timer1.
- Full Duplex serial data receiver/transmitter which holds the byte to be transmitted or received.
- Control Registers: TCON, TMOD, SCON, PCON, IP and IE which control the operations of the timers, serial ports and interrupts.
- 2 External and 3 Internal Interrupt sources. Interrupts are events which interrupt the normal sequence of execution of instructions.
- Oscillator and clock circuits

PIN DIAGRAM OF 8051

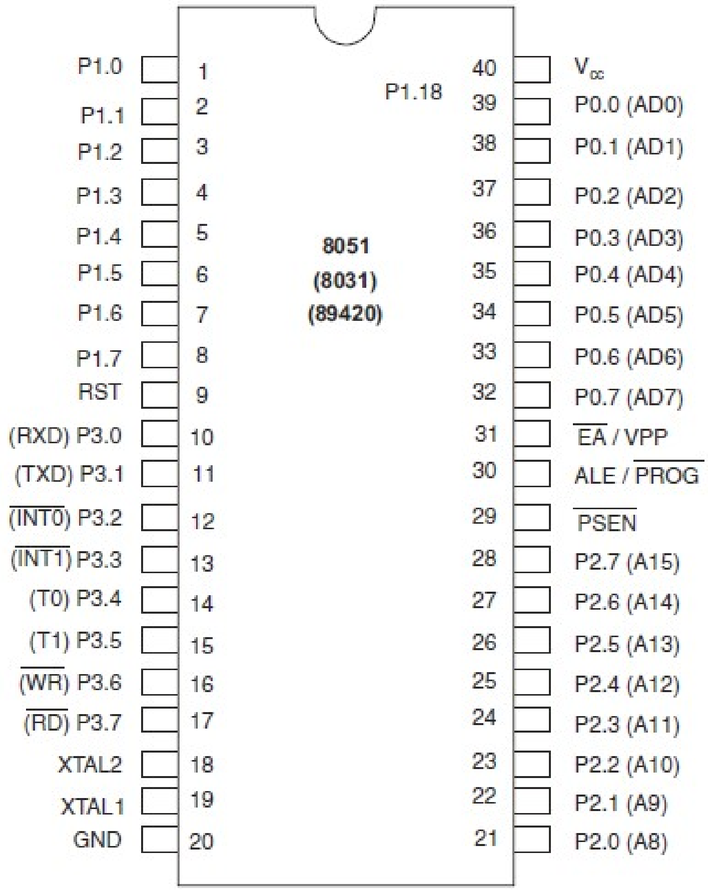


Fig: Pin diagram of 8051

Vcc:
It provides supply voltageto the chip. The voltage source is +5V.

GND: Pin 20 is the ground.

XTAL1 and XTAL2:
The 8051 has an on-chip oscillator but requires an external clock to run it. Most often a quartz crystal oscillator is connected to inputs XTAL1 (pin 19) and XTAL2 (pin 18). Typical operating frequency is 12MHz. In serial communication based applications, the operating frequency is chosen to be 11.0592MHz, in order to derive the standard universal baud rates.

RESET:

It is an input and is active high (normally low). Upon applying a high pulse to this pin, the microcontroller will reset and terminate all activities. This is often referred to as a power-on reset. Activating a power-on reset will cause all values in the registers to be lost. It will set program counter to 0000H.

$\overline{\text{EA}}$:

It is and active low I/P to 8051 microcontroller. When $(\overline{\text{EA}}) = 0$, then 8051 microcontroller access from external program memory (ROM) only. When $(\overline{\text{EA}}) = 1$, then it will access from internal and external ROM.

$\overline{\text{PSEN}}$ (Program Store Enable):

It is active low O/P signal. It is used to enable external program memory (ROM). When $\overline{\text{PSEN}}$= 0, then external program memory becomes enabled and microcontroller reads content of external memory location. Therefore it is connected to (OE) of external ROM.

ALE (address latch enable):

It is an output pin and is active high. ALE is used to demultiplex the multiplexed address-data signal of port 0 for external memory interfacing. It indicates that the bits on AD7-ADo are address bits. (The address bus will be enabled during the 1st clock cycle as the ALE pin goes high i.,e logic '1' during the first half cycle. During 2nd and 3rd clock cycles it goes low i.e., logic '0' indicating the address & data bus (AD0-AD7) is for data.)

Port 0(p0.0 to p0.7):

It is 8-bit bi-directional I/O port. It is bit/ byte addressable. During external memory access, it functions as multiplexed data and low-order address bus AD0-AD7.

Port 1 (p1.0 to p1.7):

It is 8-bit bi-directional I/O port. It is bit/ byte addressable. When logic '1' is written into port latch then it works as input mode. It functions as simply I/O port and it does not have any alternative function.

Port 2 (p2.0 to p2.7):

It is 8-bit bi-directional I/O port. It is bit/ byte addressable. During external memory access it functions as higher order address bus (A8-A15).

Port 3(p3.0 to port 3.7):

It is 8-bit I/O port. In an alternating function each pins can be used as a special function I/O pin.

P3.0-RxD:

It is an Input signal. Through this I/P signal microcontroller receives serial data of serial communication circuit.

P3.1-TxD:

It is O/P signal of serial port. Through this signal data is transmitted.

P3.2- (INT0):
It is external hardware interrupt I/P signal. Through this user, programmer or peripheral interrupts to microcontroller.

P3.3-(INT1):
It is external hardware interrupt I/P signal. Through this user, programmer or peripheral interrupts to microcontroller.

P3.4- T0:
It is I/P signal to internal timer-0 circuit. External clock pulses can connects to timer-0 through this I/P signal.

P3.5-T1:
It is I/P signal to internal timer-1 circuit. External clock pulses can connects to timer-1 through this I/P signal.

P3.6-[$\overline{\text{WR)}}$]:

It is active low write O/P control signal. During External RAM (Data memory) access it is generated by microcontroller. when $\overline{\text{[WR]}}$=0, then it performs write operation.

P3.7-$\overline{\text{[RD]}}$:

It is active low read O/P control signal. During External RAM (Data memory) access it is generated by microcontroller. When $\overline{\text{[RD]}}$=0, then it performs read operation from external RAM.

MEMORY ORGANISATION:

The 8051 has two types of memory and these are Program Memory and Data Memory. Program Memory (ROM) is used to permanently save the program being executed, while Data Memory (RAM) is used for temporarily storing data and intermediate results created and used during the operation of the microcontroller. The following figure shows the memory organization of 8051 microcontroller.

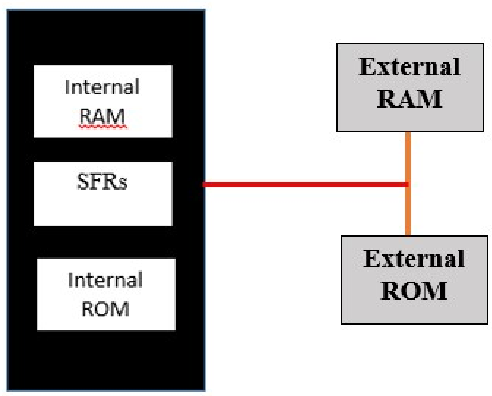
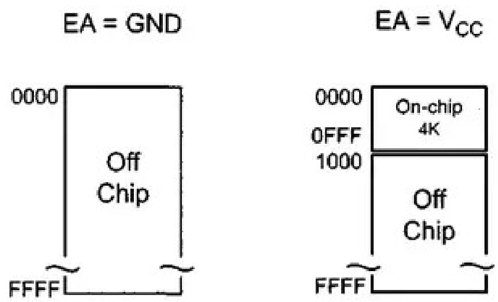


Figure: Memory organization

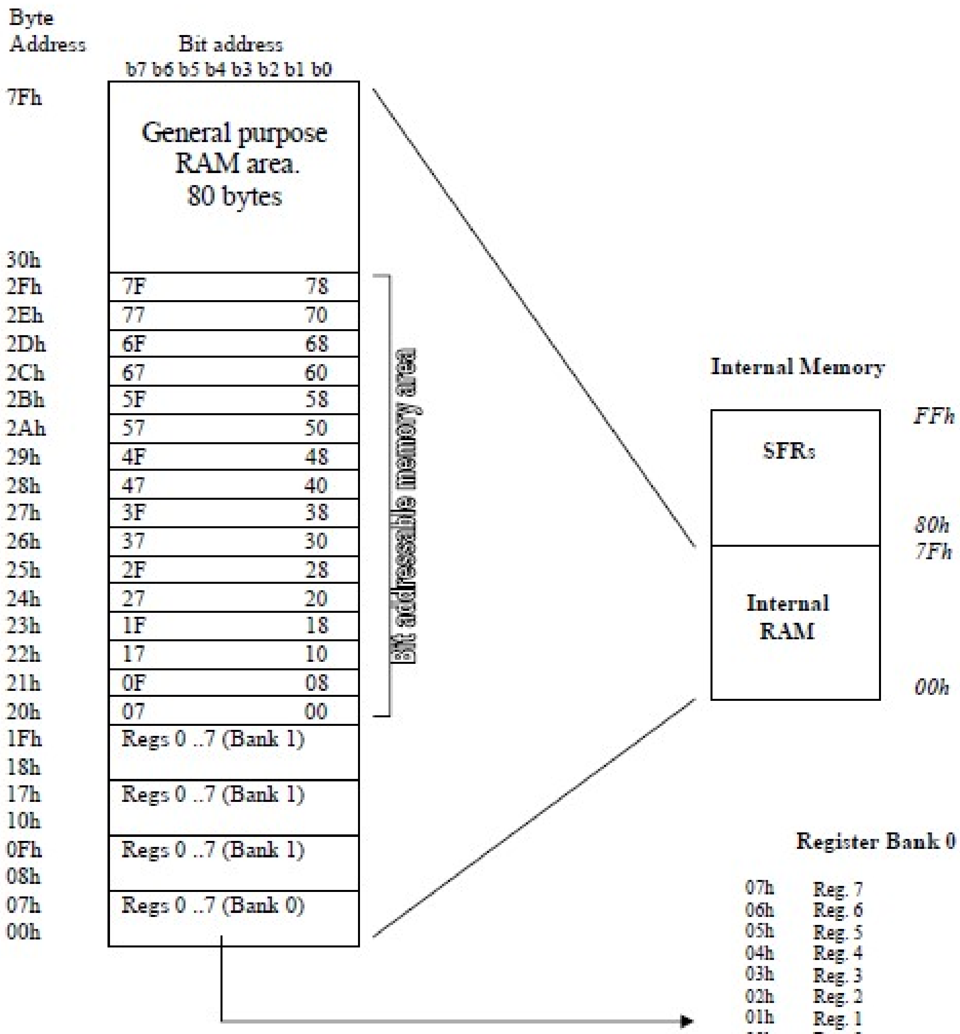
Program Memory (ROM):

- The program memory organization for 8051 family is as shown in figure.
- 8051 microcontroller has an on chip internal program ROM of 4K size and if needed we can add an external memory of size 60K maximum by interfacing. Hence total 64K size memory is available for 8051 microcontroller.
- By default, the External Access (EA) pin should be connected Vcc its mean that instructions are fetched from internal memory initially. When we cross the internal limit of memory (4K), control of program will automatically goes to external memory and remaining instructions will fetch from external ROM.
- If we wants only external memory i.e. to fetch instruction from only external memory means if we want bypass internal program ROM, then we have to must connect External Access (EA) pin to ground as shown in fig.



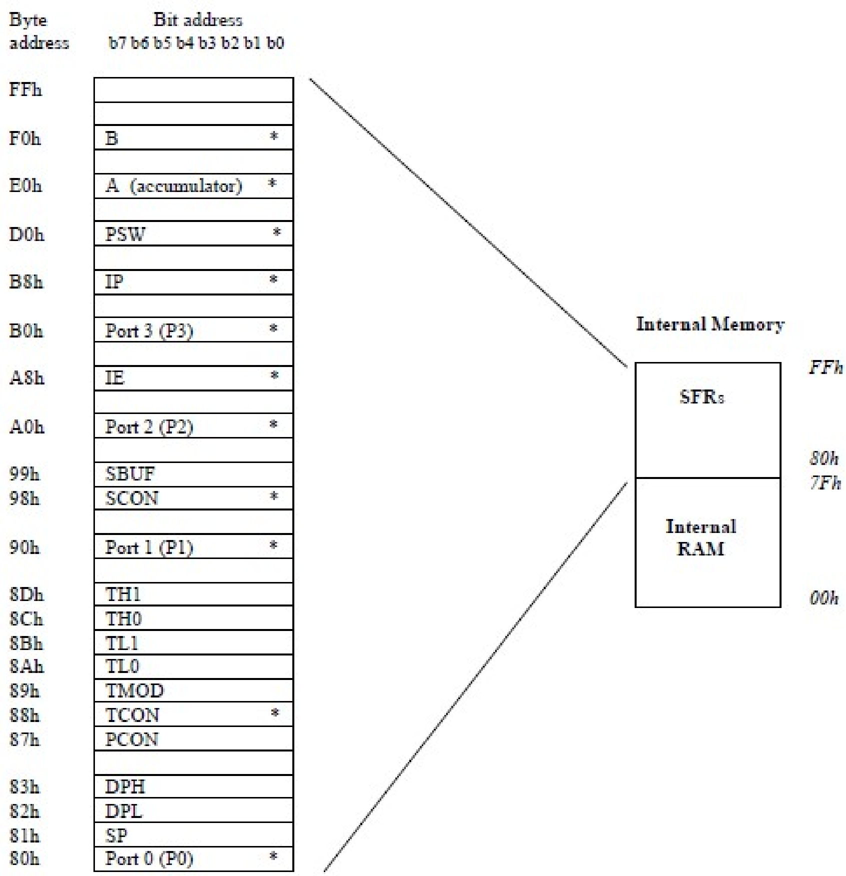
Data memory (RAM) :

- In the 8051 family, 8051 has total 128 bytes of internal data RAM and we can interface external data memory up to 64K. Hence, total size of data memory in 8051 can be upto external 64K + internal 128 bytes.
- Internal RAM of 8051 is divided into 3 parts:-
  1) Register banks
  2) Bit addressable area
  3) Scratch pad area.
- There are 4 register banks in 8051 bank 0, 1, 2 and 3. Each bank has 8 registers of 1 byte R0, R1…R7 respectively. Hence, register banks consist of the lowest 32 bytes of on chip RAM as shown in fig. At a time only one register bank can be selected for operations and bank registers are accessed using mnemonics R0..R1.. etc. By default register bank 0 is selected when we reset the system.
- The bit addressable area is 16 bytes next to register banks. We can access each bit separately of bit addressable area, Each bit have unique address of bit addressable area.The area of bit addressable space of 8051 is usually used to store bit variables. Address range 20H to 2FH (total 128 bits) is nothing but bit addressable area as shown in fig. Each bits can be accessed from 00H to 7FH within this 128 bits from 20H to 2FH.A bit variable can be set with a command such as SETB and cleared with a command such as CLR. Sometimes programming using bit addressable area saves wastage of memory.
- The upper 80 bytes are nothing but scratch pad area which is used for general purpose storing of data. Scratch pad area is in the address range 30H to 7FH. Scratch pad area can be used for stack memory also if default stack area is insufficient. Access to this area of memory is fast compared to access to the main memory



SFR Registers:

- The SFR registers are located within the Internal Memory in the address range 80h to FFh, as shown in figure.Not all locations within this range are defined.
- Each SFR has a very specific function.
- Each SFR has an address (within the range 80h to FFh) and a name which reflects the purpose of the SFR.
- Note some of the SFR registers are *bit addressable*.



* indicates the SFR registers which are bit addressable

Few specific registers are:

- **Port Registers SFR**
  - The standard 8051 has four 8 bit I/O ports: P0, P1, P2 and P3.
  - For example Port 0 is a physical 8 bit I/O port on the 8051.
    - ✓ Read (input) and write (output) access to this port is done in software by accessing the SFR P0 register which is located at address 80h.
    - ✓ SFR P0 is also bit addressable. Each bit corresponds to a physical I/O pin on the 8051.
    - ✓ Example access to port 0:

      SETB P0.7; sets the MSB bit of Port 0

      CLR P0.7; clears the MSB bit of Port 0

- **PSW Program Status word**
  - PSW, the Program Status Word is at address D0h and is a bit-addressable register.

- It is a 8 bit register.
- Used to indicate the Arithmetic condition of ACC.

PSW0.7	PSW0.6	PSW0.5	PSW0.4	PSW0.3	PSW0.2	PSW0.1	PSW0.0
CY	AC	F0	RS1	RS0	OV	—	P

FLAG Register

Parity flag. P

- 1 – Odd number of 1 in ACC
- 0 – even number of 1 in ACC

Carry flag. C

- This is a conventional carry, or borrow, flag used in arithmetic operations.
- The carry flag is also used as the 'Boolean accumulator' for Boolean instruction operating at the bit level.
- This flag is sometimes referenced as the CY flag.
- It is used to detect error in unsigned arithmetic operation.

Auxiliary carry flag. AC

When carry is generated from D3 to D4, it is set to 1, it is used in BCD arithmetic.

$$
\begin{array}{rcccccccccl}
 & & & & \boxed{1} & & & 1 & & & \\
 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & & (0EH) \\
+ & 0 & 1 & 0 & 1 & 1 & 0 & 1 & 0 & & (5AH) \\
\hline
 & 0 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & & (38H) \\
\hline
\end{array}
$$

Overflow flag. OV

- This is a conventional overflow bit for signed arithmetic to determine if the result of a signed arithmetic operation is out of range.

Register select (RS1 and RS2)

- These two bits are used for selecting the register banks of RAM

RS1(PSW0.4)	RS0(PSW0.3)	Register Bank Select
0	0	Bank 0
0	1	Bank 1
1	0	Bank 2
1	1	Bank 3

- For selecting Bank 1, we use following commands

SETB PSW0.3 (means RS0=1)

CLR PSW0.4 (means RS1=0)

- Initially by default always Bank 0 is selected.

▪ Stack Pointer

- The Stack Pointer, SP, is an 8-bit SFR register at address 81h.
- The SP contains the address of the data byte currently on the top of the stack.
- The SP pointer in initialized to a defined address. A new data item is ‘pushed’ on to the stack using a PUSH instruction which will cause the data item to be written to address SP + 1.

▪ Data Pointer

- The Data Pointer, DPTR, is a special 16-bit register used to address the external code or external data memory.
- Since the SFR registers are just 8-bits wide the DPTR is stored in two SFR registers, where DPL (82h) holds the low byte of the DPTR and DPH (83h) holds the high byte of the DPTR.

▪ Accumulator

- This is the conventional accumulator that one expects to find in any computer, which is used to the hold result of various arithmetic and logic operations.
- Since the 8051 microcontroller is just an 8-bit device, the accumulator is, as expected, an 8 bit register.
- The accumulator, referred to as ACC or A, is usually accessed explicitly using Instructions such as:

INC A; Increment the accumulator

▪ B Register

- The B register is an SFR register at addresses F0h which is bit-addressable.
- It is used in two instructions only: i.e. MUL (multiply) and DIV (divide).
- It can also be used as a general-purpose register.

▪ Program Counter

- The PC (Program Counter) is a 2 byte (16 bit) register which always contains the memory address of the next instruction to be executed.
- When the 8051 is reset the PC is always initialised to 0000h.
- If a 2 byte instruction is executed the PC is incremented by 2 and if a 3 byte instruction is executed the PC is incremented by three so as to correctly point to the next instruction to be executed.

- A jump instruction (e.g. LJMP) has the effect of causing the program to branch to a newly specified location, so the jump instruction causes the PC contents to change to the new address value.

Stack in 8051

- RAM locations from 08H to 1FH can be used as stack. Stack is used to store the data temporarily.
- Stack is last in first out (LIFO)
- Stack pointer (SP) is an 8 bit register that indicate current RAM address available for stack or it points the top of stack.
- Initially by default at 07H because first location of stack is 08H.
- After each PUSH instruction the SP is incremented by one
- After each POP instruction the SP is decremented.

Example:
MOV R6,#25H;
MOV R1,#12H;
MOV R4,#OF3H;
PUSH 06H;
PUSH 01H;
POP 04H;