Distributed & Embedded Real-Time Systems

(0640751)

Lecture (4)

Computer Hardware Requirements for ERTSs: Microprocessors & Microcontrollers

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Lecture Outline:

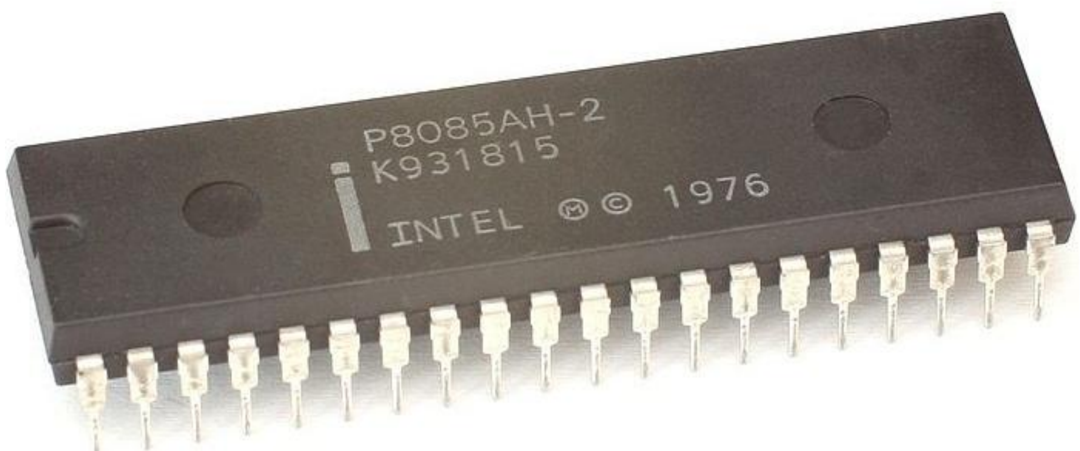
- What is a Microprocessor?
- Microprocessor Architecture.
- Microcomputer Architecture.
- CISC and RISC Architecture.
- General purpose and special purpose computers.
- Features of microcomputers and microcontrollers.

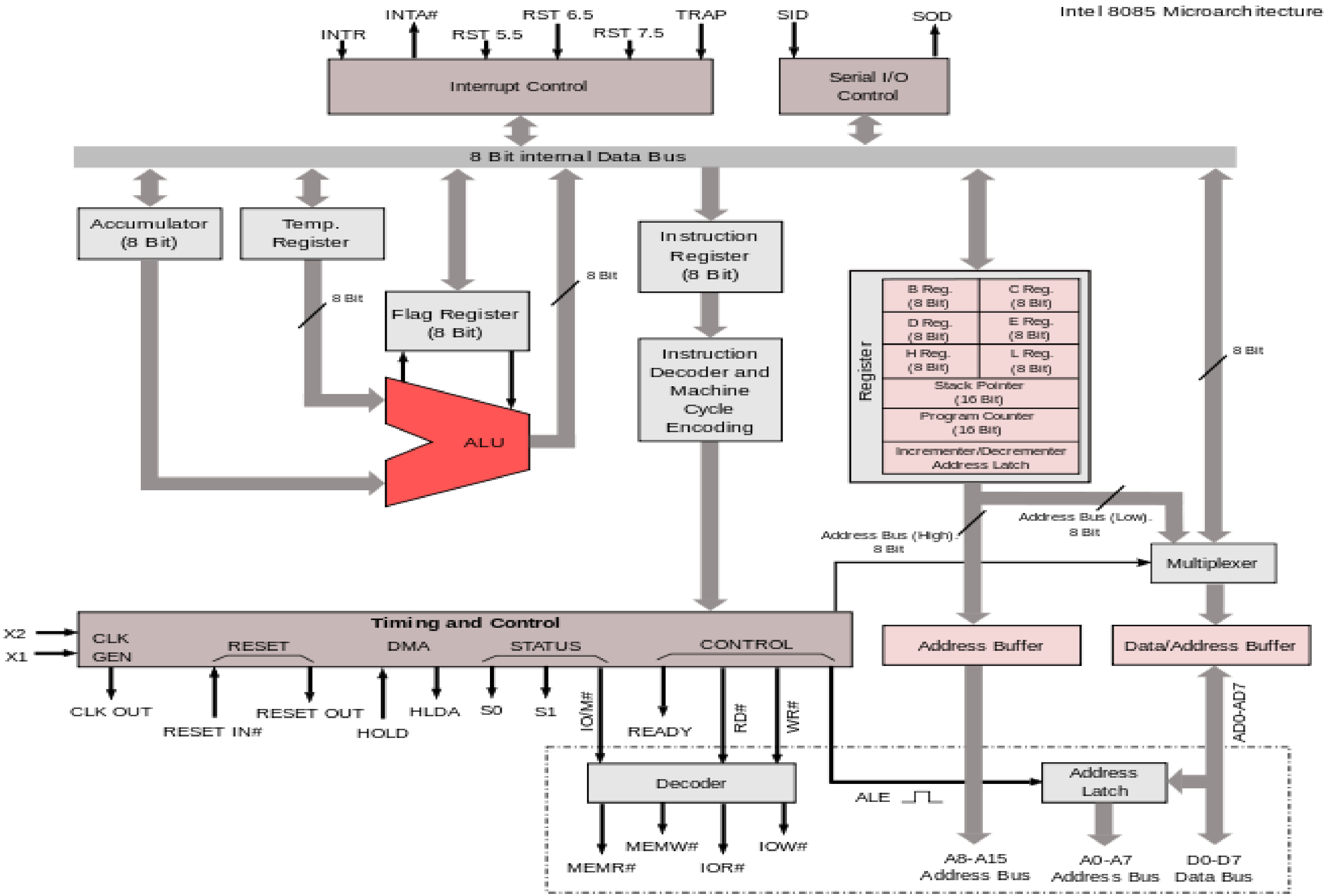
What is a Microprocessor?

It is a programmable chip contains an arithmetic logic unit, control unit and set of registers.

A **microprocessor** incorporates the functions of a computer's central processing unit (CPU) on a single chip.

The **Intel 8085** is an 8-bit microprocessor introduced by Intel in 1977. The Intel 8085 required at least an external ROM and RAM and an 8 bit address latch (both latches combined in the Intel 8755 2Kx8 EPROM / 2x8 I/O, Intel 8155 256-byte RAM and 22 I/O and 14 bit programmable Timer/Counter) so cannot technically be called a microcomputer.

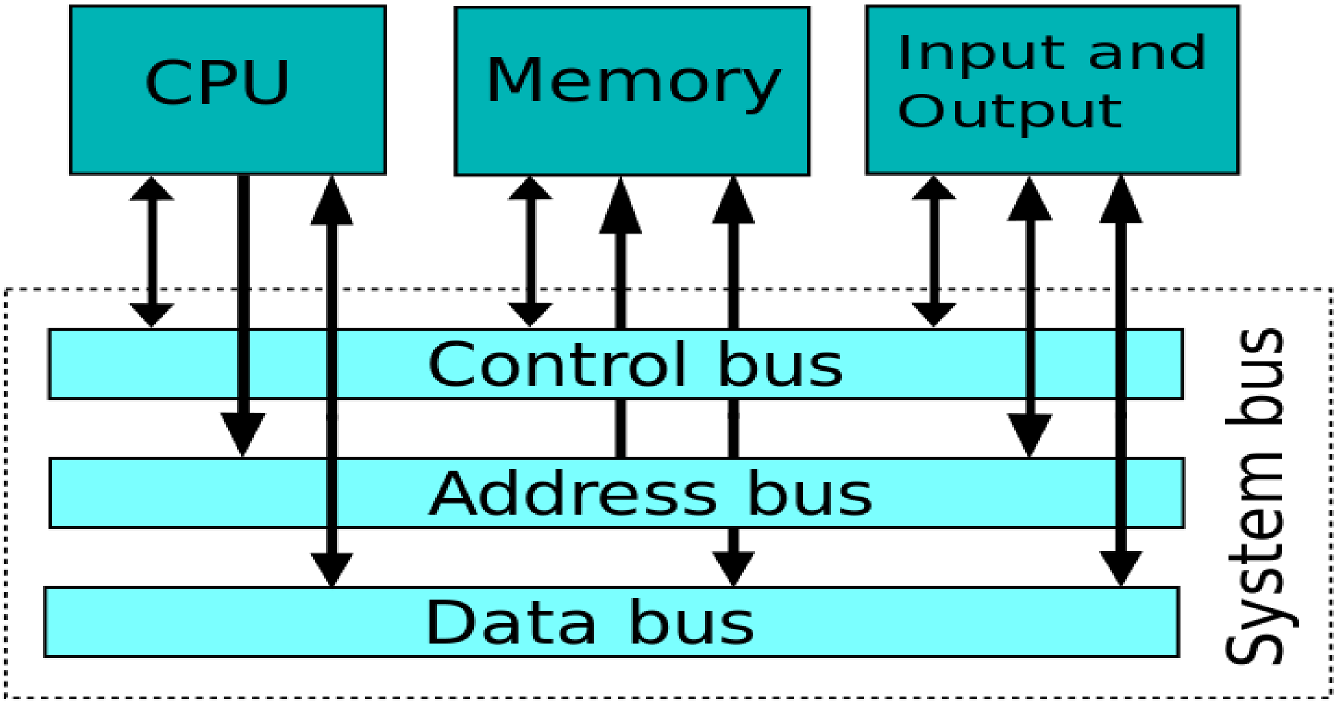


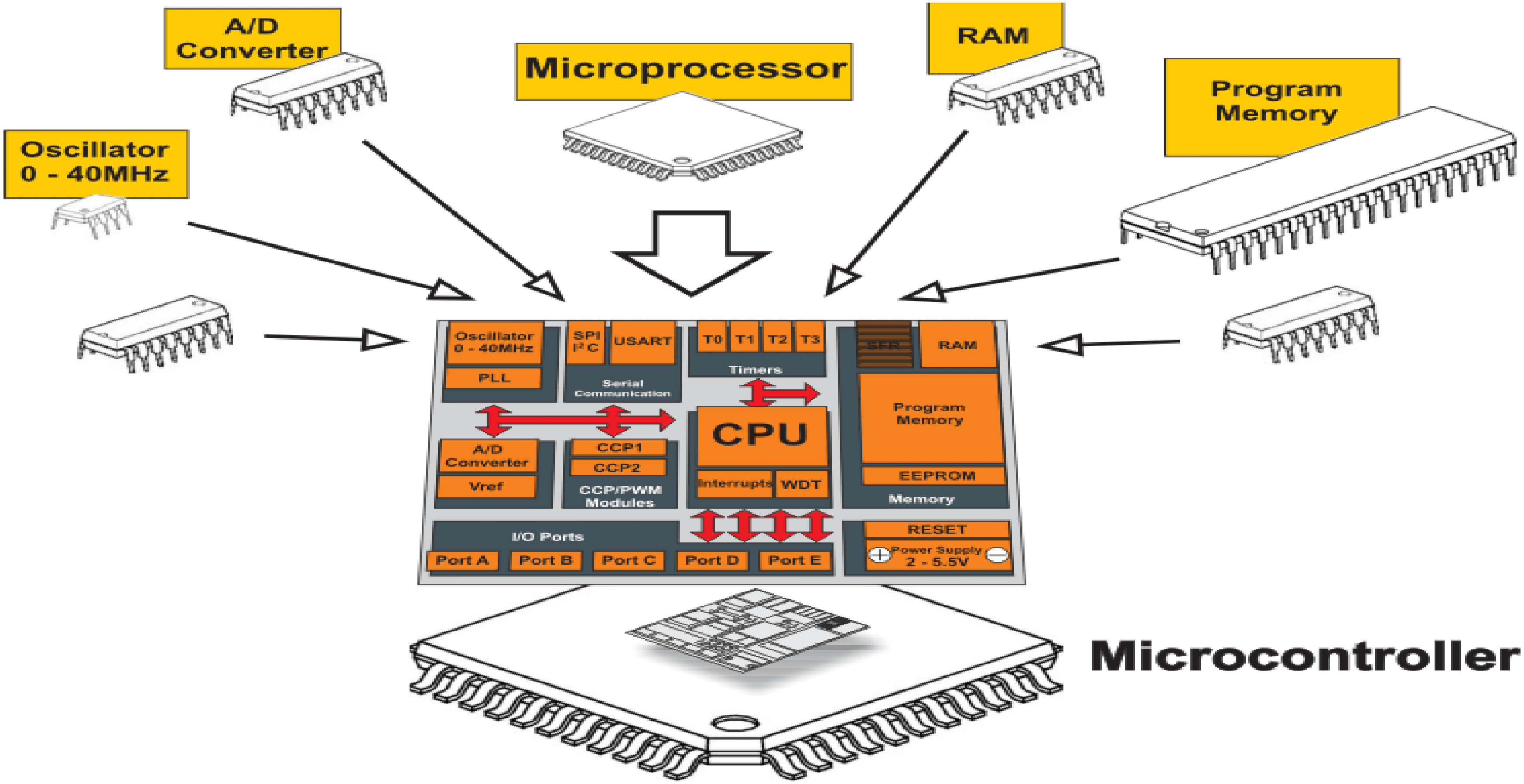

Intel 8085 Microarchitecture
INTR
INTA#
RST 5.5
RST 6.5
RST 7.5
TRAP
SID
SOD
Interrupt Control
Serial I/O Control
8 Bit internal Data Bus
Accumulator (8 Bit)
Temp. Register
8 Bit
Flag Register (8 Bit)
8 Bit
ALU
Instruction Register (8 Bit)
Instruction Decoder and Machine Cycle Encoding
Register
B Reg. (8 Bit)
C Reg. (8 Bit)
D Reg. (8 Bit)
E Reg. (8 Bit)
H Reg. (8 Bit)
L Reg. (8 Bit)
Stack Pointer (16 Bit)
Program Counter (16 Bit)
Incrementer/Decrementer Address Latch
8 Bit
Address Bus (Low) 8 Bit
Address Bus (High) 8 Bit
Multiplexer
Timing and Control
X2
X1
CLK GEN
RESET
DMA
STATUS
CONTROL
Address Buffer
Data/Address Buffer
CLK OUT
RESET IN#
RESET OUT
HOLD
HLDA
S0
S1
IO/M#
READY
RD#
WR#
AD0-AD7
Decoder
ALE
Address Latch
MEMR#
MEMW#
IOR#
IOW#
A8-A15 Address Bus
A0-A7 Address Bus
D0-D7 Data Bus

Microprocessor-Based System:

Computer system generally consists of three main parts:

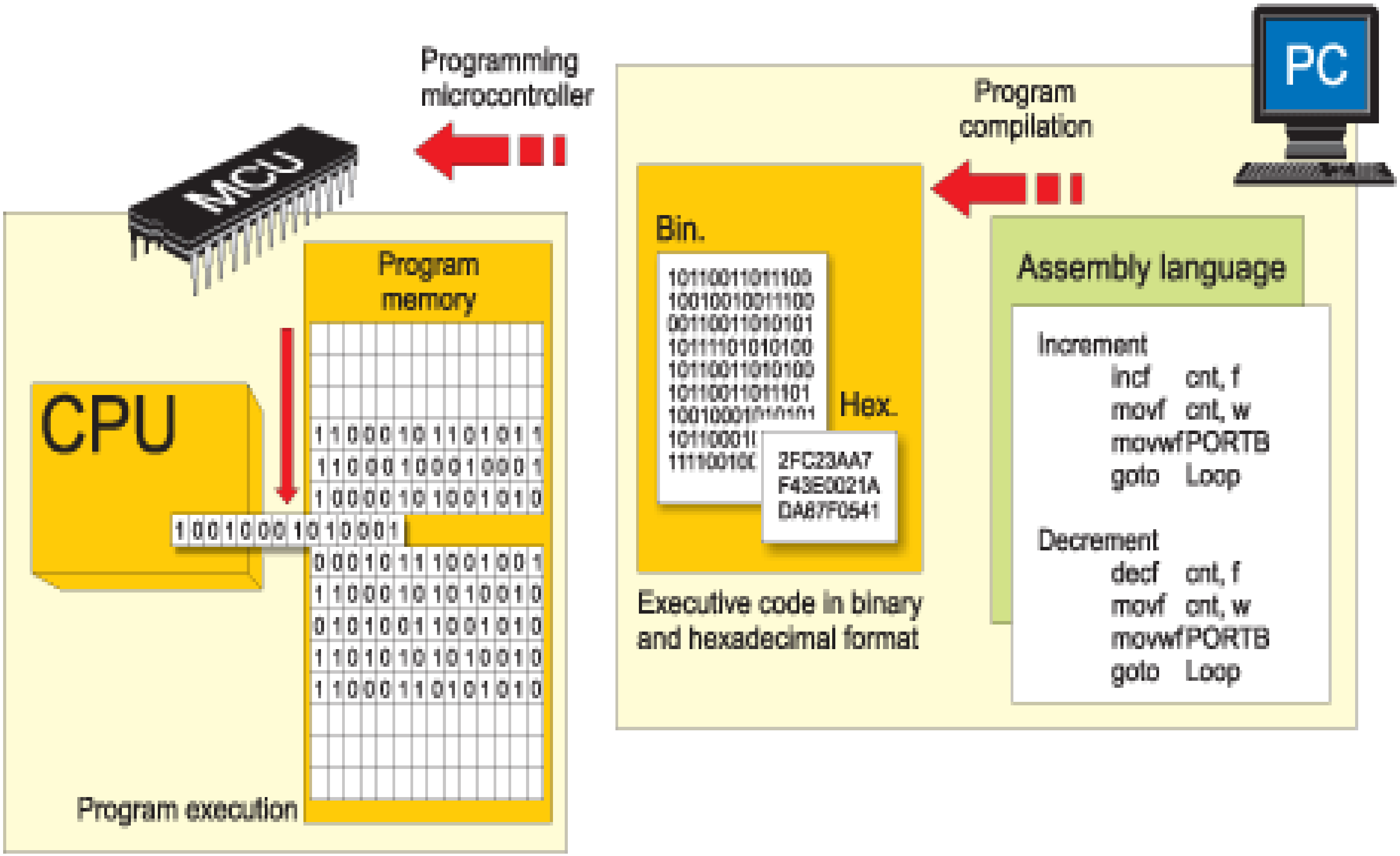
1. The CPU (Microprocessor), to process data.
2. Memory to hold the data to be processed, and
3. A variety of I/O devices (Peripherals) to communicate that data with the outside world.

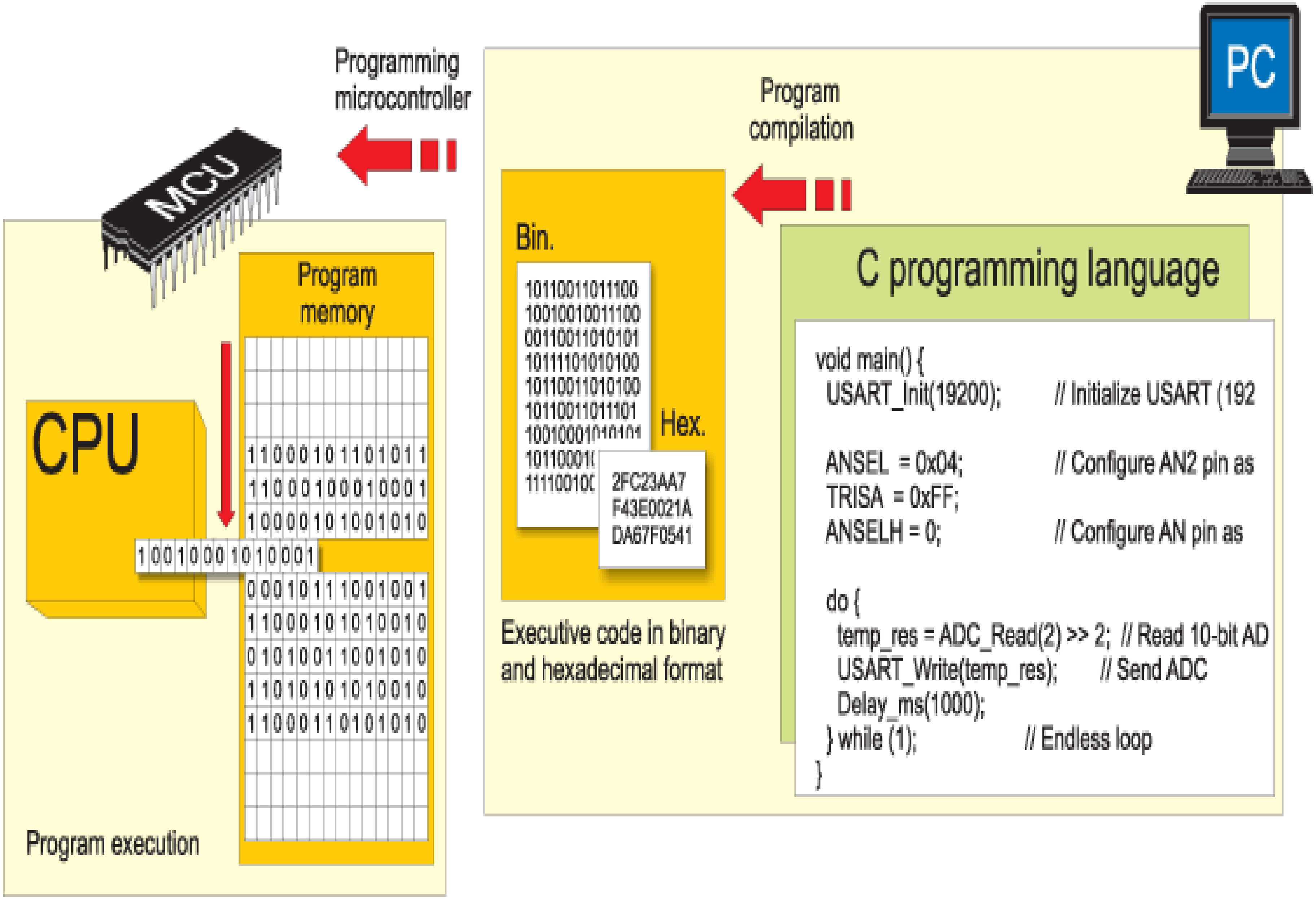




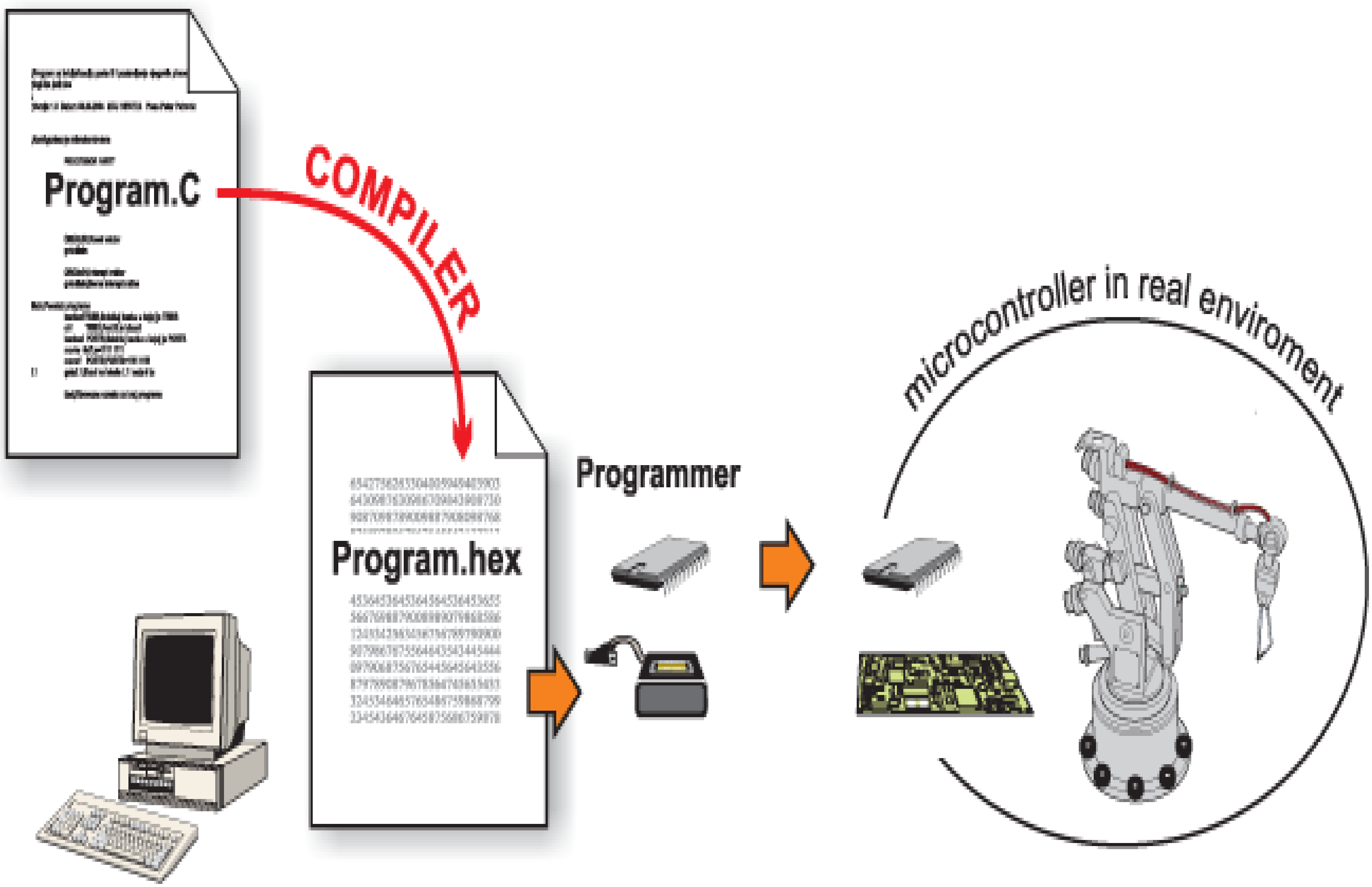
The MC is designed to be all of that in one. No other external components are needed for its application because all necessary circuits belong to peripherals are already built in it. It saves time and space needed to design a device.

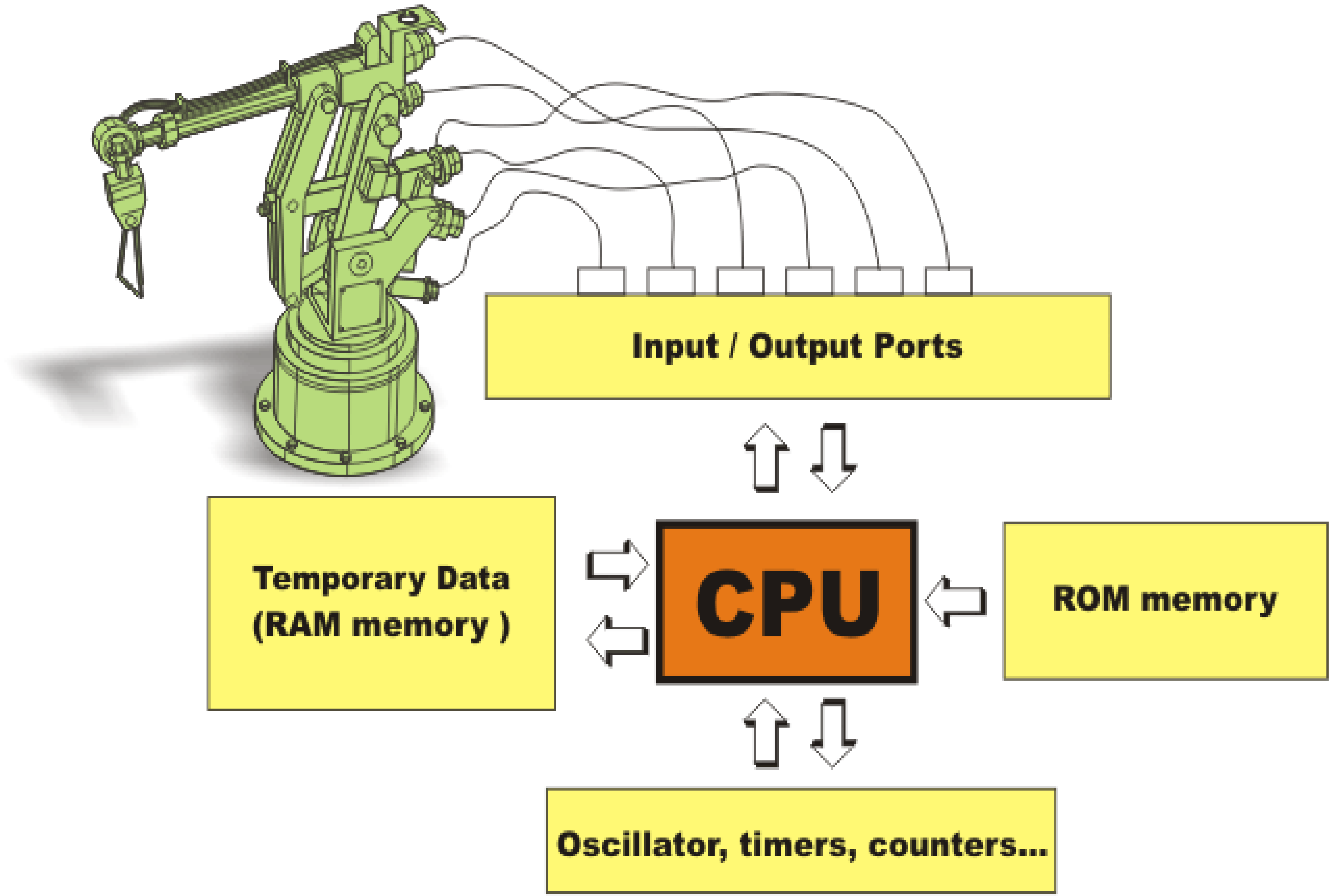
Microcontroller Programming

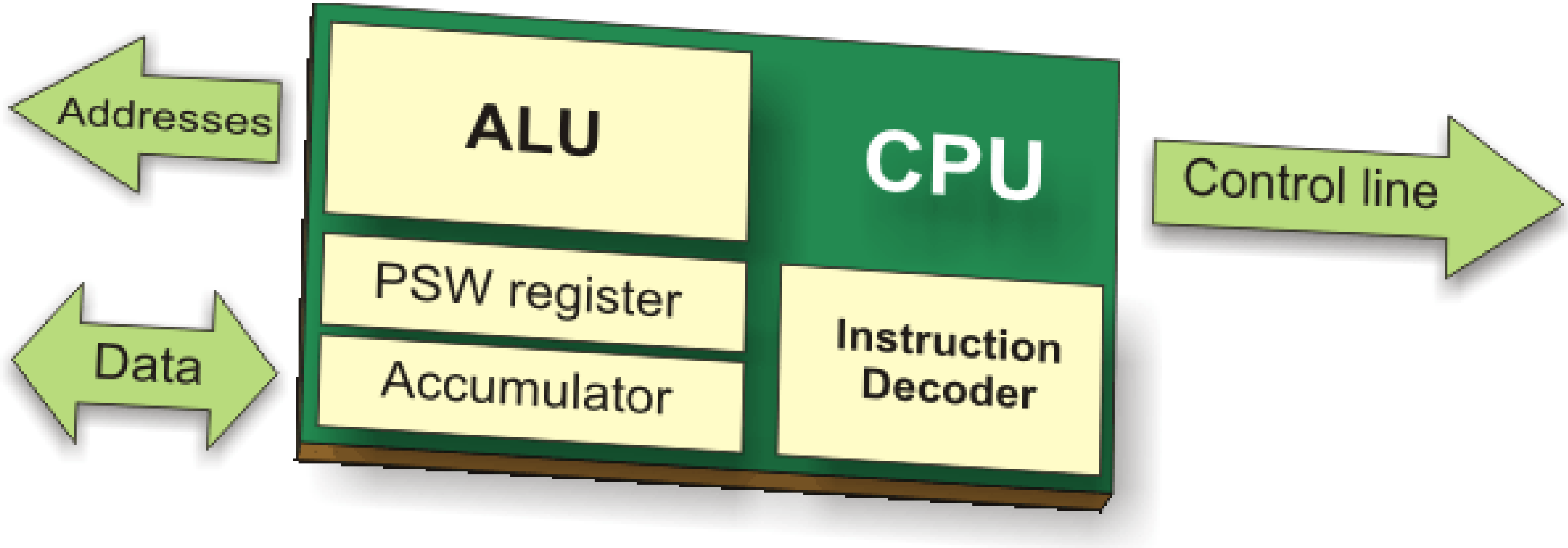




Programming
microcontroller
MCU
Program
memory
CPU
11000101101011
11000100010001
10000101001010
10010001010001
00010111001001
11000101010010
01010011001010
11010101010010
11000110101010
Program execution
PC
Program
compilation
Bin.
10110011011100
10010010011100
00110011010101
10111101010100
10110011010100
10110011011101
Hex.
2FC23AA7
F43E0021A
DA67F0541
Executive code in binary
and hexadecimal format
C programming language
void main() {
USART_Init(19200); // Initialize USART (192
ANSEL = 0x04; // Configure AN2 pin as
TRISA = 0xFF;
ANSELH = 0; // Configure AN pin as
do {
temp_res = ADC_Read(2) >> 2; // Read 10-bit AD
USART_Write(temp_res); // Send ADC
Delay_ms(1000);
} while (1); // Endless loop
}


Program.C
COMPILER
Program.hex
Programmer
microcontroller in real enviroment


Input / Output Ports
Temporary Data
(RAM memory)
CPU
ROM memory
Oscillator, timers, counters...

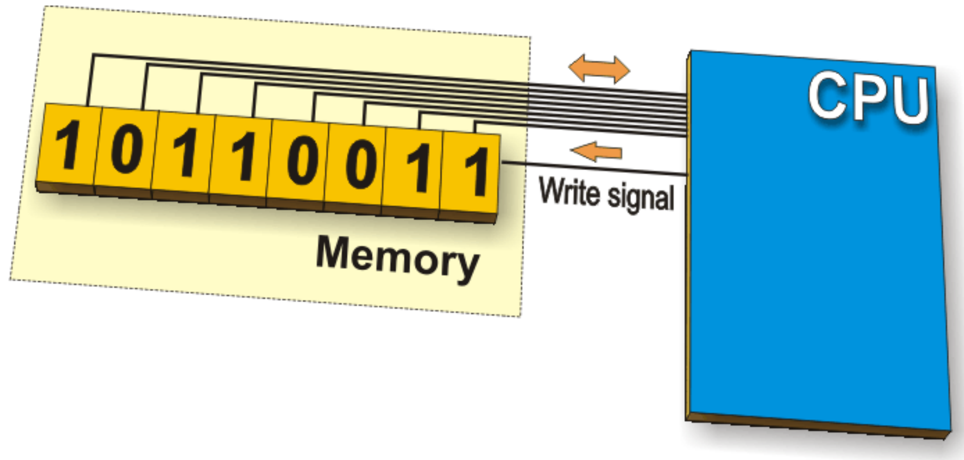


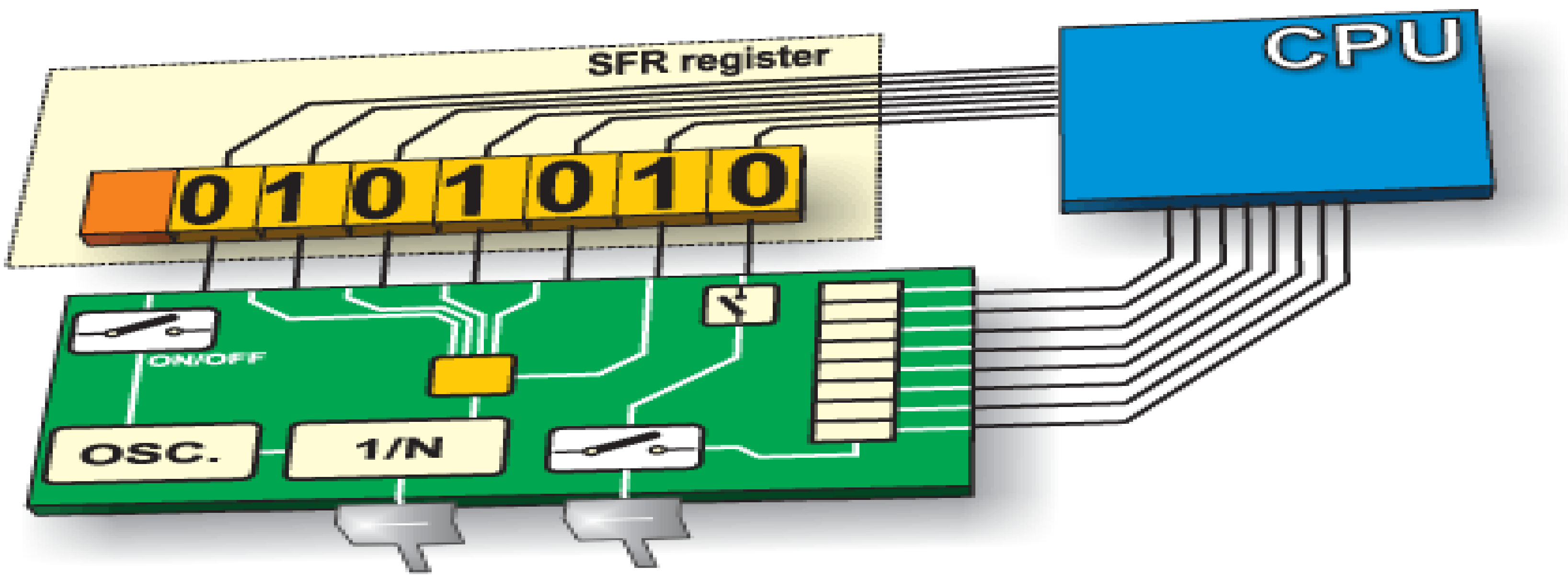
CENTRAL PROCESSOR UNIT (CPU)

- This unit monitors and controls all processes within the MC. It consists of several subunits:
- **Instruction Decoder**: to decode program instructions and run other circuits.
- **Arithmetical Logical Unit (ALU):** to perform all mathematical and logical operations upon data.
- **Accumulator (Working Reg):** is an SFR closely related to the operation of the ALU. One of the SFRs, called a *Status Register (PSW)*, is closely related to the accumulator. It shows at any given time the 'status' of a number stored in the accumulator.

Registers:

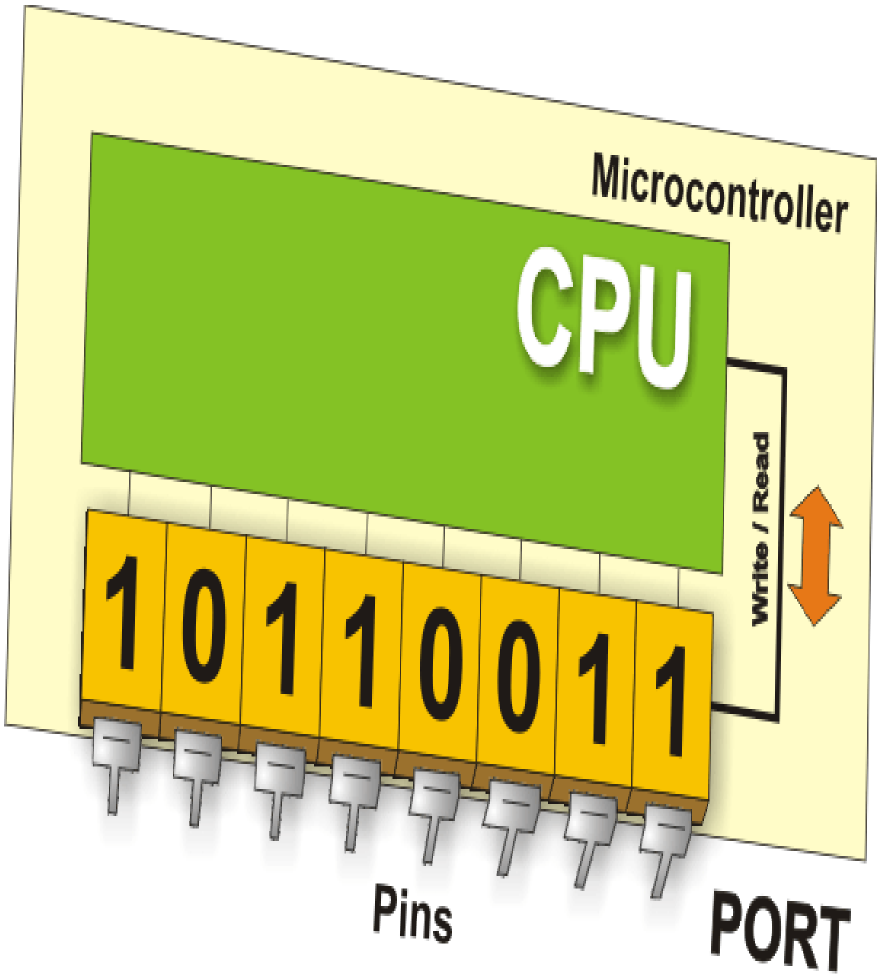
In addition to registers which do not have any special and predetermined function, every microcontroller has a number of registers (SFR) whose function is predetermined by the manufacturer.

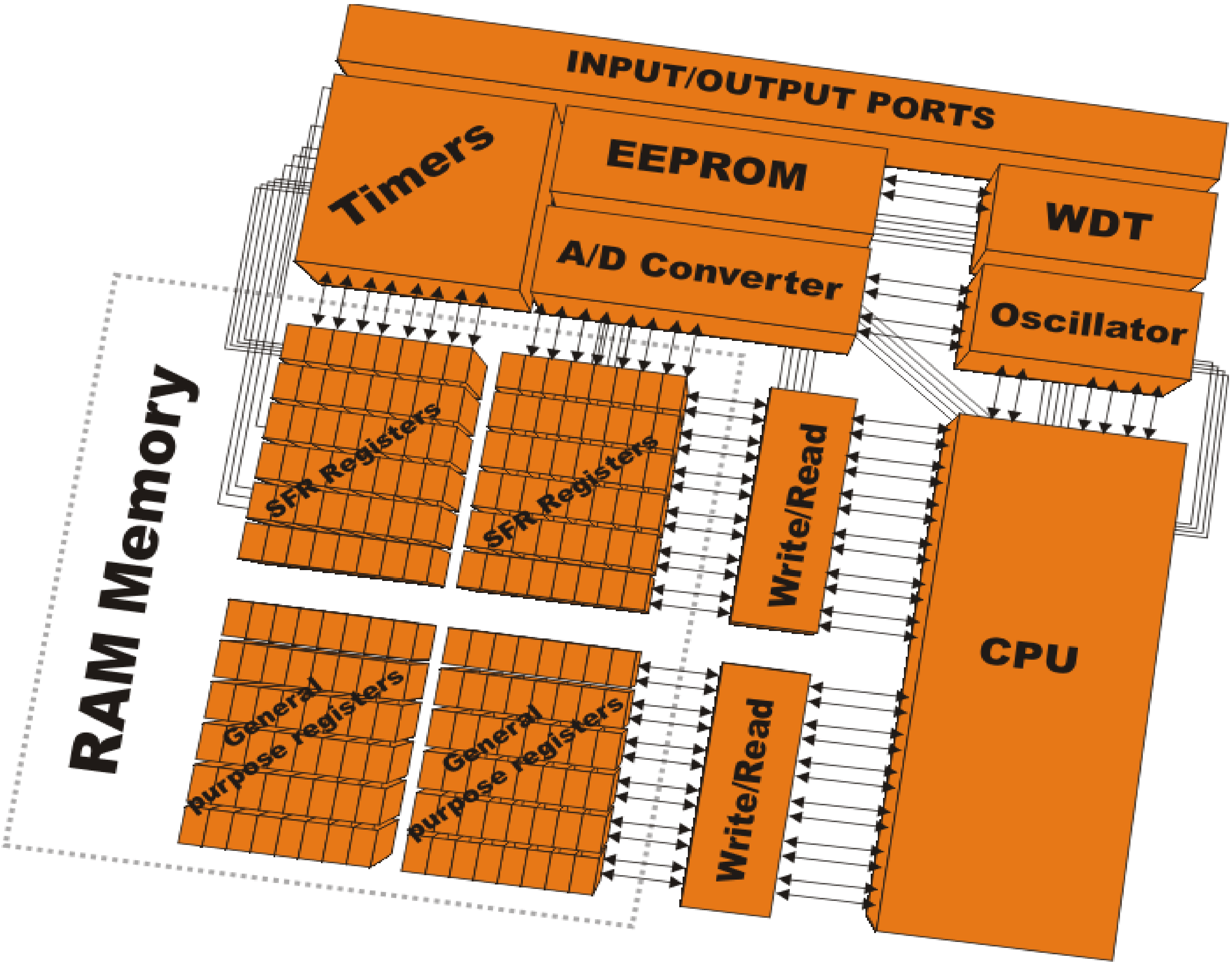




Input/Output Pins:

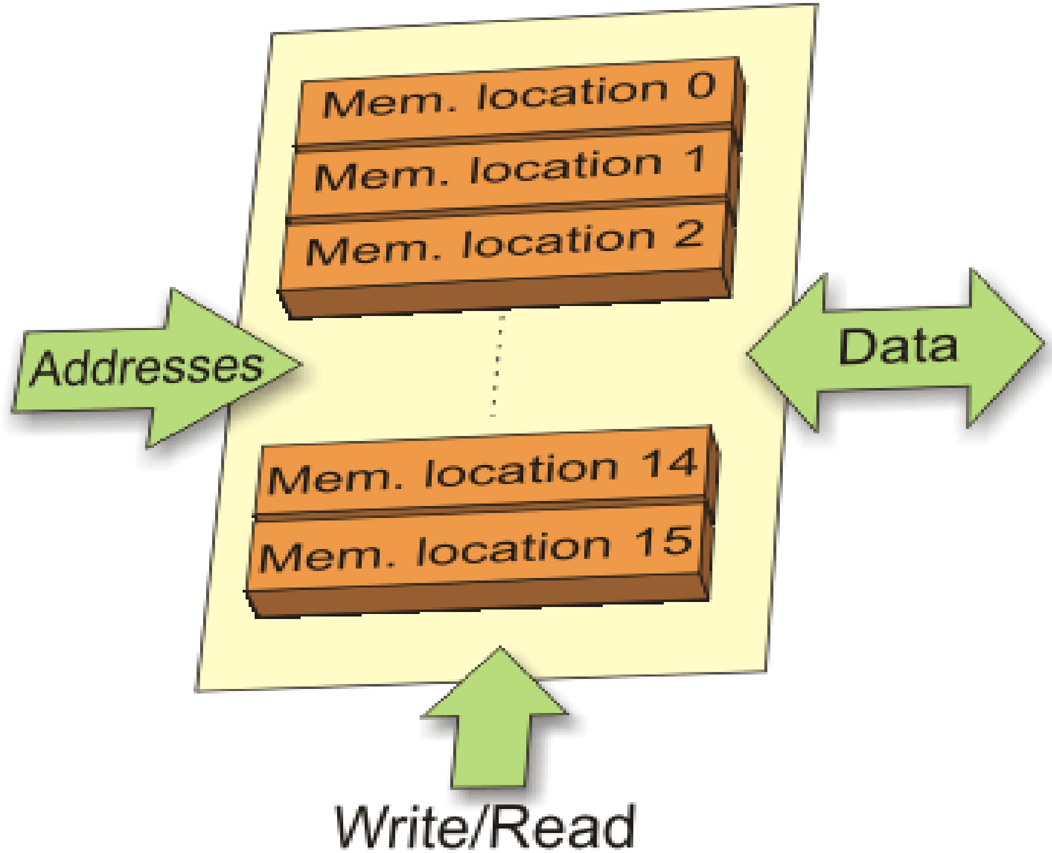
- In order to make the MC useful, it has to be connected to additional peripherals.
- Each MC has one or more registers (called ports) connected to the MC pins.
- Each I/O port is usually under control of the specialized SFR.
- For example, by writing logic one to a bit of the control register (SFR), the appropriate port pin is automatically configured as an input.




INPUT/OUTPUT PORTS
Timers
EEPROM
A/D Converter
WDT
Oscillator
RAM Memory
SFR Registers
SFR Registers
Write/Read
General purpose registers
General purpose registers
Write/Read
CPU

MEMORY UNIT

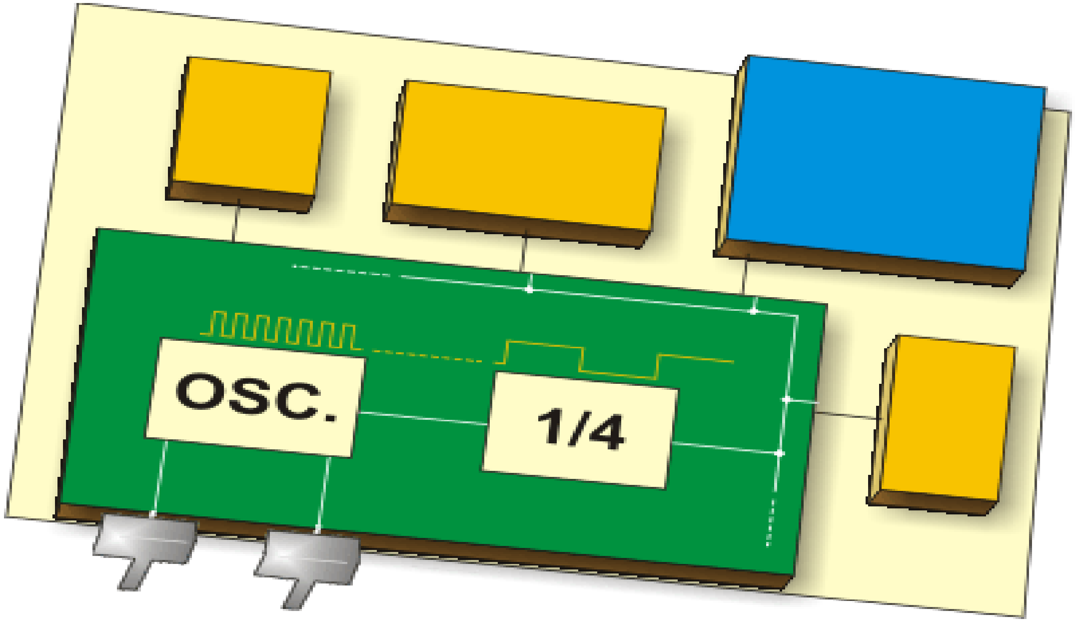
- Memory is part of the MC used for data storage.
- There are several types of memory within the MC: RAM, ROM, PROM, EPROM, EEPROM, Flash Memory.



Flash Memory:

The content of this memory can be written and cleared practically an unlimited number of times.

MCs with Flash ROM are ideal for learning, experimentation and small-scale production.



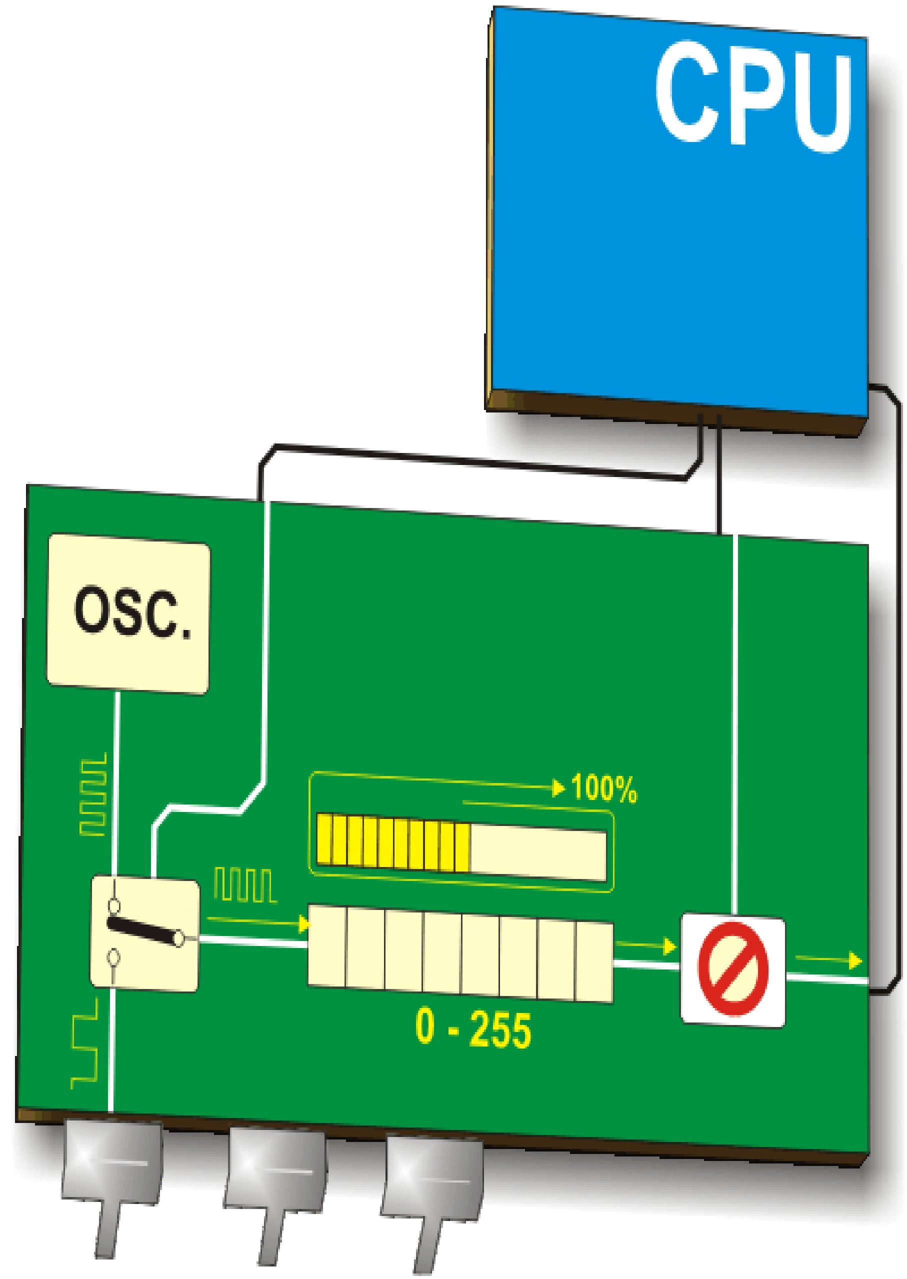
OSCILLATOR

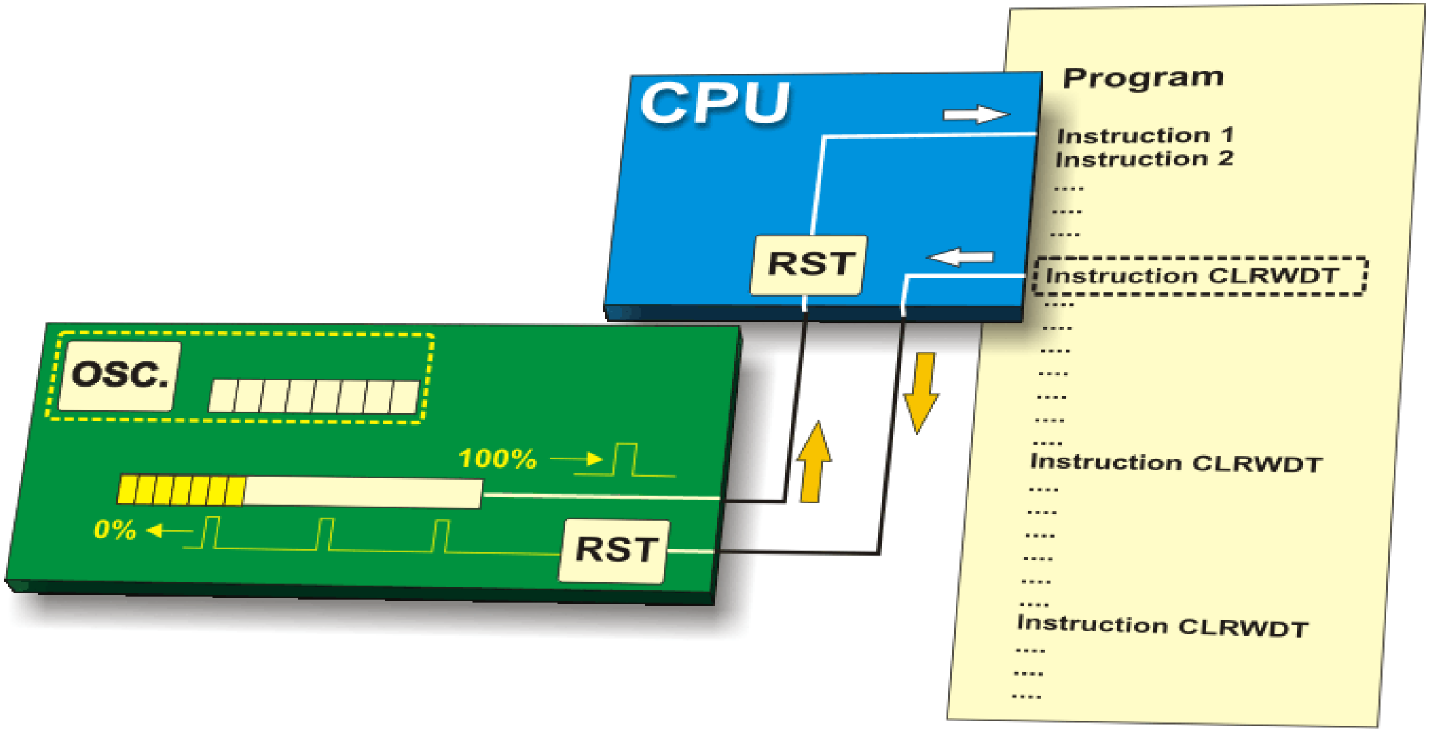
- Pulses generated by the oscillator enable synchronous operation of all circuits within the MC.
- The oscillator is usually configured so as to use quartz crystal or ceramic resonator for frequency stability, but it can also operate as a stand-alone circuit (RC oscillator).
- It is important to say that instructions are not executed at the rate imposed by the oscillator itself, but several times slower.

Timer/Counter:

•If it is necessary to measure time between two events, it is sufficient to count up pulses generated by this oscillator. This is exactly what the timer does.

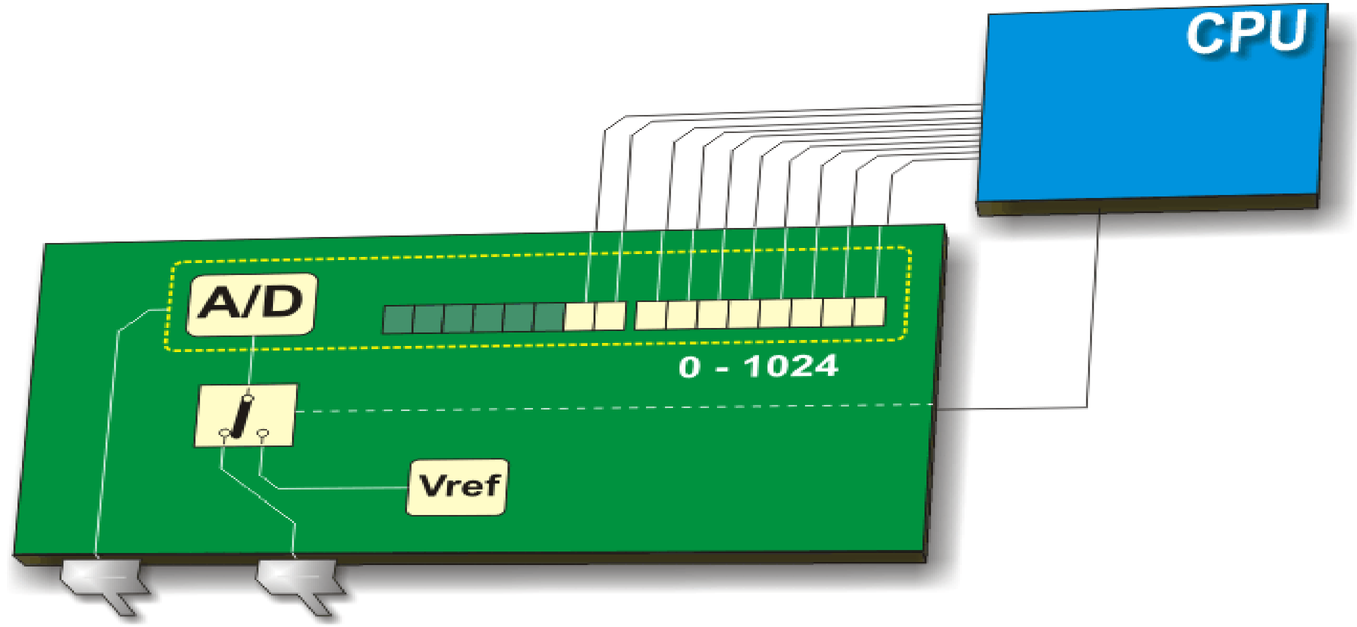
•If the timer receives pulses from the MC input pin, then it turns into a counter.





WATCHDOG TIMER (WDT):

- A WDT is a timer connected to a completely separate RC oscillator within the microcontroller.
- If the watchdog timer is enabled, every time it counts up to the maximum value, the microcontroller reset occurs and the program execution starts from the first instruction. The point is to prevent this from happening by using a specific command.

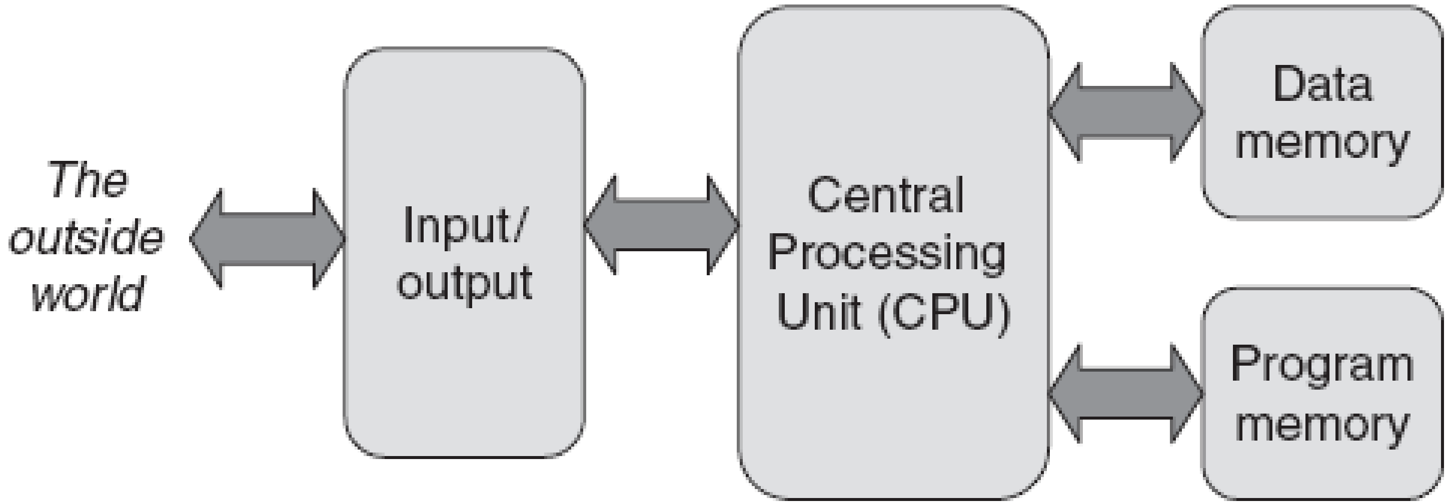


A/D CONVERTER:

- External signals are usually analog signals different from those the MC understands (ones and zeros) and have to be converted.
- An analogue to digital converter is an electronic circuit which converts continuous signals to discrete digital numbers.
- This circuit converts an analogue value into a binary number and passes it to the CPU for further processing. This module is therefore used for input pin voltage measurement (analogue value).

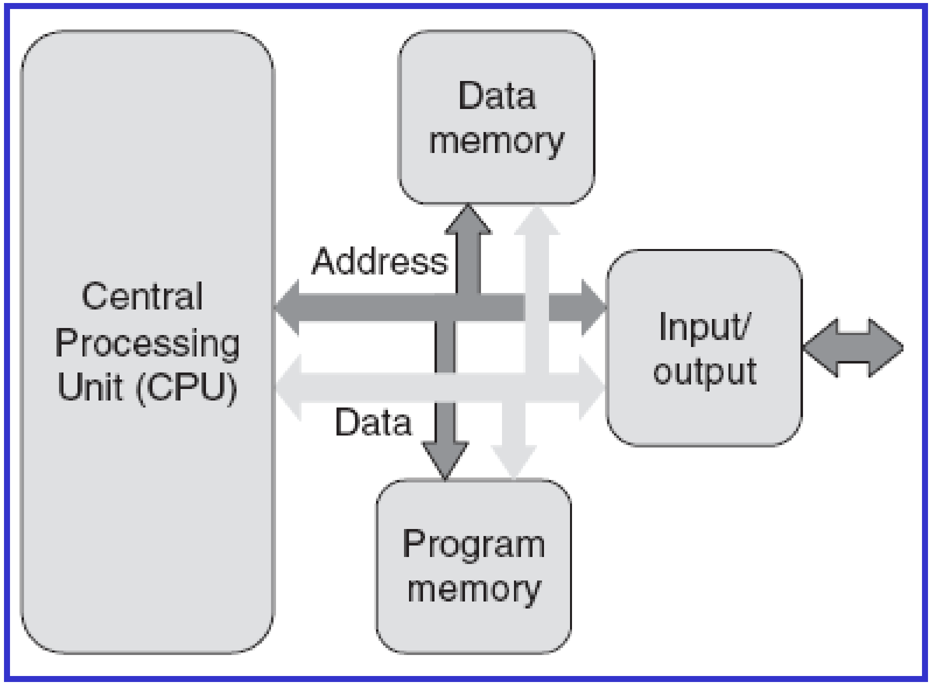
Microcomputers & Microcontrollers:

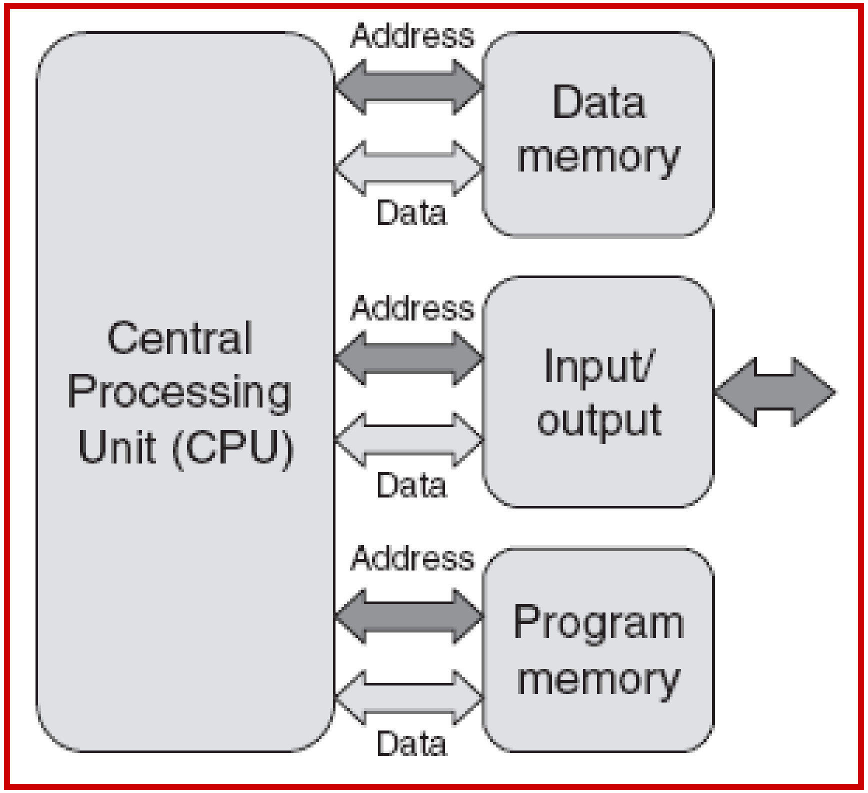
- General purpose microprocessors include the Intel xx86 series, Motorola 680xx series, National 32xxx series, and the Zilog Z8000 series.
- The ALU together with control unit and the general purpose registers make up the CPU.
- The CPU, memory and input/output units represent a microcomputer. The CPU in a single chip microcomputer or a microcomputer board is called microprocessor.



Computer Architecture:

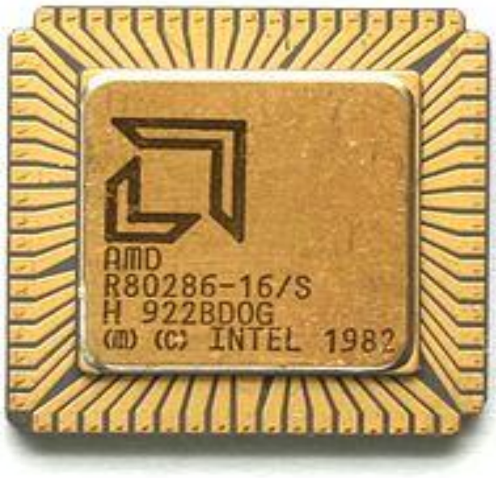
1. The Von Neumann System.
2. The Harvard System.





CISC and RISC Architectures:

A **complex instruction set computer** (**CISC**) is a computer where single instruction can execute several low-level operations (such as a load from memory, an arithmetic operation, and a memory store) and/or are capable of multi-step operations or addressing modes within single instructions. Th CPU has large number of instructions and limited number of registers.



Reduced instruction set computer (RISC) is a computer based on the insight that simplified instructions can provide higher performance if this simplicity enables much faster execution of each instruction. The CPU has limited number of instructions and large number of registers.

RISC vs. CISC

The difference between CISC and RISC becomes evident through the basic computer performance equation:

$$\text{CPU Time} = \frac{\text{seconds}}{\text{program}} = \frac{\text{instructions}}{\text{program}} \times \frac{\text{avg. cycles}}{\text{instruction}} \times \frac{\text{seconds}}{\text{cycle}}$$

RISC systems shorten execution time by reducing the *clock cycles per instruction* (i.e. simple instructions take less time to interpret)

CISC systems shorten execution time by reducing the *number of instructions per program*

Example for RISC vs. CISC

Consider the the program fragments:

CISC

```
mov ax, 10
mov bx, 5
mul bx, ax
```

RISC

```
       mov ax, 0
       mov bx, 10
       mov cx, 5
Begin  add ax, bx
       loop Begin
```

The total clock cycles for the CISC version might be:

(2 movs x 1 cycle) + (1 mul x 30 cycles) = 32 cycles

While the clock cycles for the RISC version is:

(3 movs x 1 cycle) + (5 adds x 1 cycle) + (5 loops x 1 cycle) = 13 cycles

RISC vs. CISC Summary

RISC	CISC
• Simple instructions, few in number	• Many complex instructions
• Fixed length instructions	• Variable length instructions
• Complexity in compiler	• Complexity in microcode
• Only **LOAD/STORE** instructions access memory	• Many instructions can access memory
• Few addressing modes	• Many addressing modes

General-Purpose Computer :

1. **CPU : Features :**
   - Word length.
   - Addressing methods.
   - Information transfer rates.
   - Instruction set .
   - No. of registers.
   - Interrupt structure.

2. Storage:

- RAM, ROM, EPROM and auxiliary storage unit .
- DMA for fast I/O information transfer.

3. Input and Output:

- Process I/O
- Operator I/O
- Computer I/O

4. Bus structure:

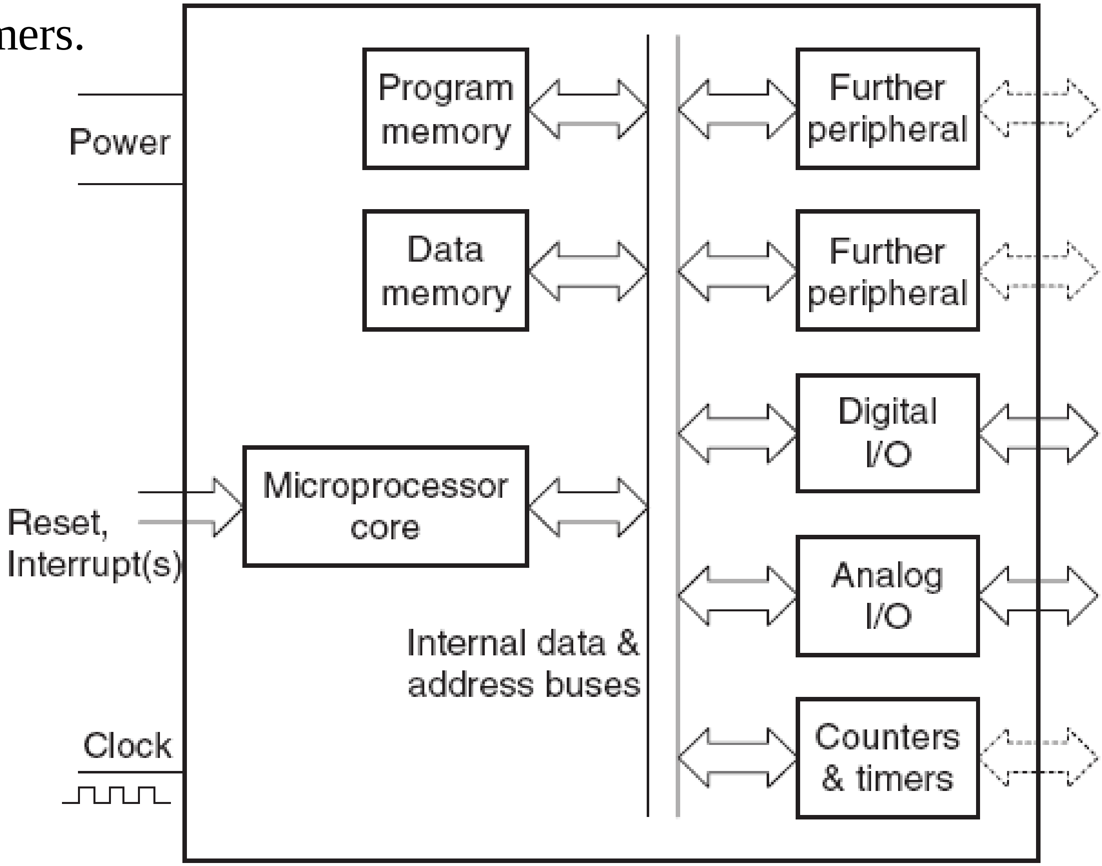
- Mechanical (physical) structure
- Electrical
- Functional

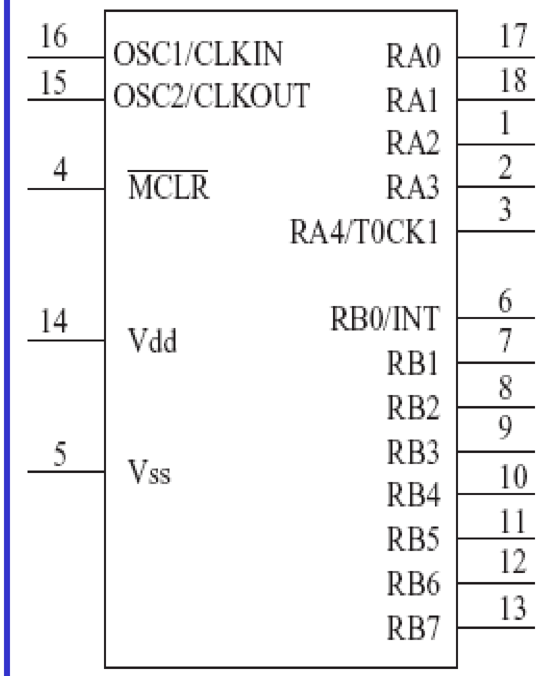
Specialized Computers:

- Specialized processors have been developed for two main purposes:
  - Safety-critical applications.
  - Increased computation speed .
- For safety-critical applications , use RISC computers.
- The advantage of simplifying the instruction set is:
  1. The possibility of formal verification (using math. proofs) that the logic of the processor is correct.
  2. It is easier to write assemblers and compilers for simple instruction set.
- Many different forms of parallel computer architecture have been used SIMD, MISD, and MIMD .
- Digital signal processors .

Single Chip Microcontrollers:

- Small amount of RAM and EPROM , it can be extended .
- Instruction set .
- DAC and ADC
- Interrupt structure
- I/O lines .
- Timers.





PIC16F84 pin configuration

Microcontroller Selection:

Comparison of PIC families

PIC family	Stack size (words)	Instruction word size	Number of instructions	Interrupt vectors
12CXXX/12FXXX	2	12- or 14-bit	33	None
16C5XX/16F5XX	2	12-bit	33	None
16CXXX/16FXXX	8	14-bit	35	1
17CXXX	16	16-bit	58, including hardware multiply	4
18CXXX/18FXXX	32	16-bit	75, including hardware multiply	2 (prioritised)

Device number	No. of pins*	Clock speed	Memory (K = Kbytes, i.e. 1024 bytes)	Peripherals/special features
16F84A	18	DC to 20 MHz	1K program memory, 68 bytes RAM, 64 bytes EEPROM	1 8-bit timer 1 5-bit parallel port 1 8-bit parallel port
16F873A	28	DC to 20 MHz	4K program memory 192 bytes RAM, 128 bytes EEPROM	3 parallel ports, 3 counter/timers, 2 capture/compare/PWM modules, 2 serial communication modules, 5 10-bit ADC channels, 2 analog comparators
16F874A	40	DC to 20 MHz	4K program memory 192 bytes RAM, 128 bytes EEPROM	5 parallel ports, 3 counter/timers, 2 capture/compare/PWM modules, 2 serial communication modules, 8 10-bit ADC channels, 2 analog comparators

The PIC16F84 Microcontroller:

- The 16F84A architecture is representative of all 16 Series microcontrollers, with Harvard structure, pipelining and a RISC instruction set.
- The PIC 16F84A has a limited set of peripherals, chosen for small and low-cost applications. It is thus a smaller member of the family, with features that are a subset of any of the larger ones.
- A particular type of memory location is the Special Function Register, which acts as the link between the CPU and the peripherals.
- Reset mechanisms ensure that the CPU starts running when the appropriate operating conditions have been met, and can be used to restart the CPU in case of program failure.
- The parallel port allows ready exchange of digital data between the outside world and the controller CPU.
- It is important to understand the electrical characteristics of the parallel port and how they interact with external elements.
- A microcontroller needs a clock signal in order to operate. The characteristics of the clock oscillator determine speed of operation and timing stability, and strongly influence power consumption.
- Interrupts and counter/timers are important hardware features of almost all microcontrollers. They both carry a number of important hardware and software concepts, which must be understood.