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Computer Architecture and Organization-I

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The machine *computer* came in 1940s.

Conceptualized from the Latin word 'computare' ('calculate' or count), it came to be just as essential to the study of chaotic system.

Study on *computer architecture* is the accumulation of concepts, developed and refined over years - it leads to this powerful computing machine - today's *Computer*.

## 0.1 Today's Computer

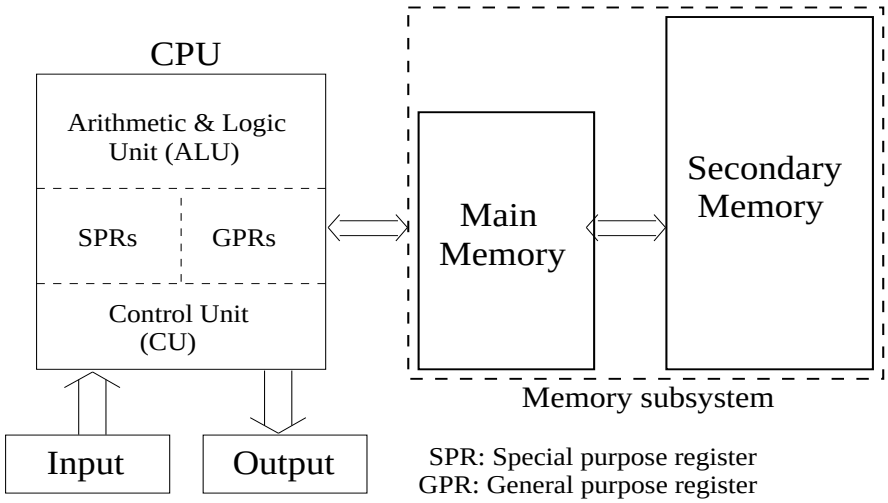
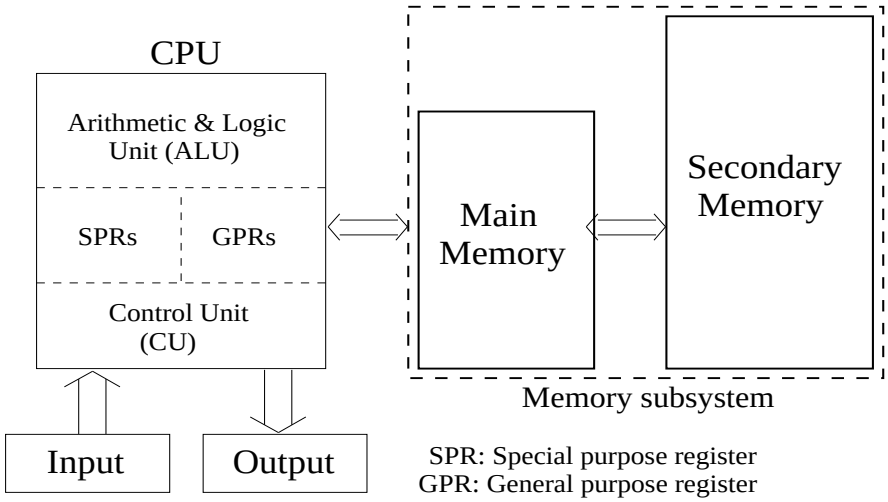



Figure 1: Basic organization of a machine computer

Today's conventional computer stores the set of instructions in its memory and executes (process) them one by one.

Five major components of a computer (Figure 1) are - central processing unit (CPU), main memory (MM), input, output and secondary memory (SM) or backing store.




**A** The central processing unit (CPU)

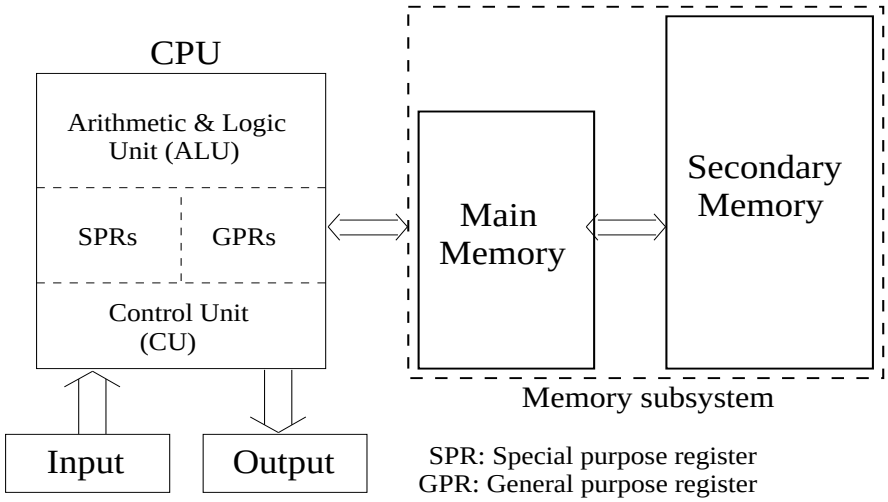
1. Is the site of all processing.

2. It contains registers

Circuitry to perform arithmetic and logical operations (ALU)

Control circuit (CU) that generates control signals to manage (synchronize) all the operations within a CPU and the machine computer as a whole

In a machine computer, there can be many processors (e.g. Input/Output processors, co-processors, etc.) other than the CPU. However, CPU is the main (central) processing unit of a computer.




**B** The main memory (MM)

1. Stores the program (set of instructions) which is to be executed by the CPU.

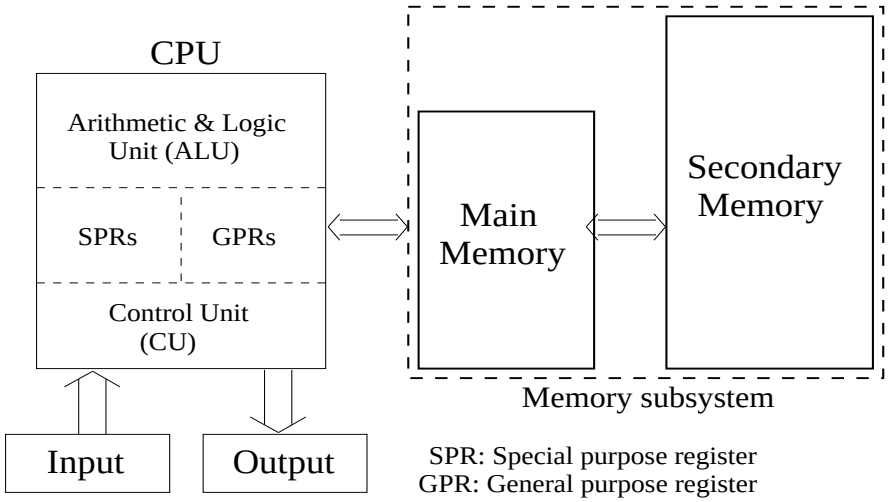
2. An instruction of a program can not be executed by the CPU unless it is brought into MM which is directly interfaced with the CPU.

3. The major main memory features are-

- Relatively high speed. Its access time is of the order of nano-second ($ns$),[1]. For example, DRAM speed (access time) is $<$50 $ns$.
- Relatively small capacity, normally, few giga[2] bytes.
- Normally, volatile. However, a small portion of MM, is non-volatile ROM. The common example - BIOS ROM.

[1] $10^{-3} \Rightarrow$ milli ($m$), $10^{-6} \Rightarrow$ micro ($\mu$), $10^{-9} \Rightarrow$ nano ($n$), $10^{-12} \Rightarrow$ pico ($p$), $10^{-15} \Rightarrow$ femto ($f$), $10^{-18} \Rightarrow$ atto ($a$), $10^{-21} \Rightarrow$ zepto ($z$), and $10^{-24} \Rightarrow$ yocto ($y$).

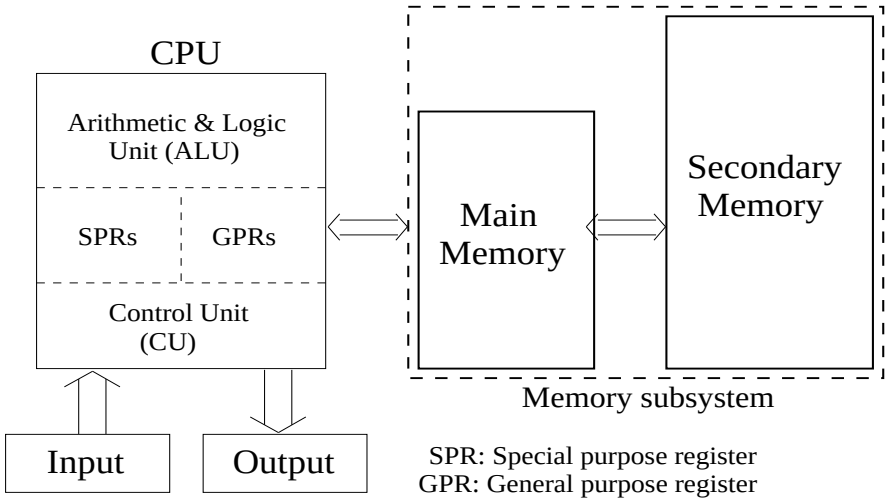
[2] 1 giga bytes (GB) = $10^9$ bytes.




**C** The secondary memory (SM)

1. Used for long term storage of program and data.
2. The important features are:

- Comparatively low speed.
- Cost/bit is very low.
- Non-volatile type.
- Large capacity (even more than a terabyte ($10^{12}$ bytes)).




**D** Input-output - such devices provide means to establish communication between a user and computer.

1. A wide varieties of input/output devices can be interfaced with the CPU.

These differ as per the information coding style, mechanical/electrical properties, mode of data communication, etc.

Example: communication can follow serial or parallel data transfer; the coding style can be Hollerith/ASCII[3], etc.

The speed variation of input/output devices ranges from few bytes to mega bits[4].

The mode of data transfer between a CPU and the input/output devices follows different options - synchronous, asynchronous, interrupt driven and the direct memory access (DMA).

[3] ASCII (American Standard Code for Information Interchange) was proposed in 1960.

[4] Keyboard speed can be 0.01 Kbyte/s (10 byte/s). Mouse speed is 0.02 Kbyte/s (20 bytes/s). Modem speed is in Kbyte/s .....

**E** Today's computer is nothing but an information processor (Figure 2).

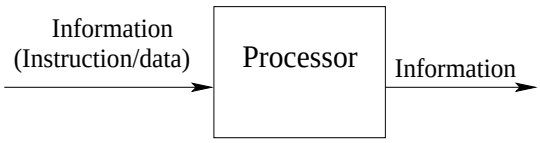



Figure 2: The computer

It can input (accept), compute (process), and output (form) information as desired.

Computing (information processing) is an age old practice. It had a long journey to achieve its present shape. We will explore this in AT-I and AT-II.

## 0.2 The History of Modern Computer

First electronic computer - Electronic Numerical Integrator and Computer (ENIAC, 1946). The ENIAC occupied a space of 30×50 sq ft. It used about 18,000 vacuum tubes (Figure 3).

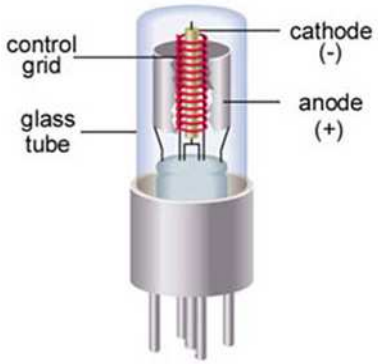



Figure 3: Vacuum tube

Operated (programming/data entry) by switch setting and changing cables.

The system had to switch off every few hours because of over-heating.

The programming in that machine could not be stored for a run.

### 0.2.1 Stored program computers

Stored program computer is capable of storing programs in its memory.

EDVAC (Electronic Discrete Variable Computer) was the first stored program computer.

Rapid changes in technology and design opened up new directions in the development of machine computer.

For better understanding of the development in electronic computer design, its performance and architecture, we categorize history of its development as generations.

## 0.3 Computer Generations

History of development of modern electronic computers is categorized based on the device technology, the system architecture, processing mode and language used.

### 0.3.1 First generation (1940-1955)

ENIAC was introduced in 1946, weighing 30 tons, consisted of 18,000 vacuum tubes, 1,500 relays, 70,000 registers and more than 10,000 capacitors and inductors.

Power consumption of the ENIAC was almost 200 kilowatts.

The area covered by it was 15000 square foot.

ENIAC could compute at most 5000 additions per second.

In 1946-48, von Neumann and his colleagues began the design of a new stored program computer, referred to as IAS (immediate access store) computer.

This effectively set the base of our modern computer architecture.

The important features of first generation machine computers were

- The vacuum tube as basic device technology.
- Relay circuits for realization of the switch.
- The memory, designed around the mercury delay lines.
- Very primitive input/output devices.
- The serial circuitry for computer hardware.
- Programing language was the machine language or assembly language.
- The arithmetic introduced was the bit-serial arithmetic and fixed point.

### 0.3.2 Second generation (1950-1965)

Second generation computers: transition from vacuum tube to transistor technology.

The transistor was invented in 1947.

Important second generation computer: TRADIC (transistorized digital computer).

TRADIC was made of 800 transistors in 1954.

It was of 3 cubic foot, and could perform million logical operations per second.

TRADIC was operated on 100 kilowatt of power.

Basic features of such second generation computers were

- Transition from vacuum tube to transistor technology.
- Use of magnetic core memory.
- Use of magnetic drum for secondary storage.
- Introduction of HLL such as FORTRAN, ALGOL, COBOL etc.
- Use of index registers in CPU.
- Introduction of floating point arithmetic hardware.
- Introduction of special processors such as I/O processors.
- Batch processing of jobs was in place.

#### 0.3.2.1 Third generation (1960-1975)

Third generation computers introduced the IC technology.

The main features of third generation machine computers were

- Introduction of IC technology. The SSI and MSI were in place.
- Semiconductor memory gradually replaced magnetic core memory.
- Introduction of pipelining architecture.
- Introduction of cache memory in between CPU and main memory.
- Introduction of enriched high level languages.
- Introduction of multiprogramming, time sharing and virtual memory OS.

### 0.3.3 Fourth generation (1970 - present)

The PCs developed around the microprocessors are the product of fourth generation.

LSI/VLSI technology enables low cost highly efficient portable computers.

Key features of fourth generation computers are

- Extensive use of LSI and VLSI circuits.
- Extension of high level languages to handle both scalar and vector data.
- Introduction of parallel processing techniques for high speed computation. Massively parallel processors (MPP) are in place.

### 0.3.4 Fifth generation (1990 - ...)

Fifth generation computer turns to massive number of CPUs for added performance.

Features of fifth generation computers are

- Introduced ULSI/VHSIC (very-high-speed integrated circuits) processors.
- Radical departure from von Neumann architecture.
- Hardware facilities for knowledge processing.
- Design to handle voice and picture input-output.
- Natural language processing.
- Expert computer systems target replacement of expert human brains.

## 0.4 Technology Trends

VLSI technology made it possible today that the performance of today's microprocessor is even comparable with that of a supercomputer (Figure 4).

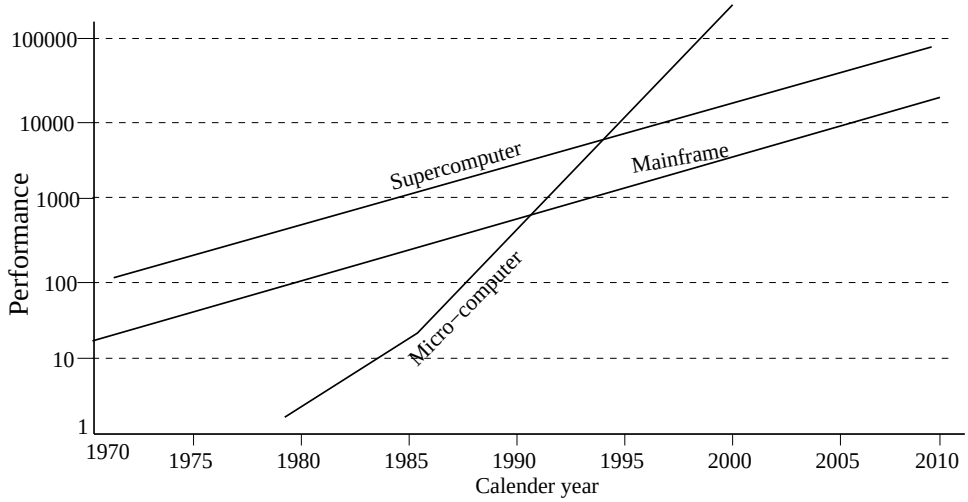



Figure 4: Performance trend

It is due to the improved compaction density within a chip (processor/memory etc.). The figures in Table 1 show the compaction density of different IC technologies.

Table 1: VLSI compaction density

| Technology | Type | Compaction density |
|---|---|---|
| SSI | TTL | 10 gates/chip |
| MSI | TTL | 100 gates/chip |
| LSI | TTL | 1000 gates/chip |
| VLSI | MOS | 10,000 to 1,00,000 gates/chip |
| ULSI | MOS | Million transistors/chip |