

Unit 1

Introduction to Microprocessor

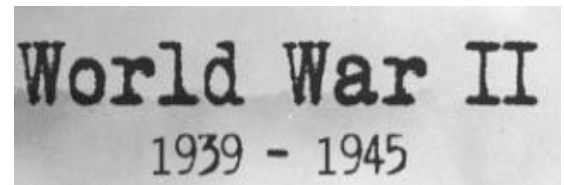
Definition of Computer

- ✓ Computer is a programmable machine.
- ✓ Computer is a machine that manipulates data according to a list of instructions.
- ✓ Computer is any device which aids humans in performing various kinds of computations or calculations.



There are five generations of computer:

- ✓ **First generation – 1946 – 1958**
- ✓ **Second generation – 1959 – 1964**
- ✓ **Third generation – 1965 – 1970**
- ✓ **Fourth generation – 1971 – today**
- ✓ **Fifth generation – Today to future**

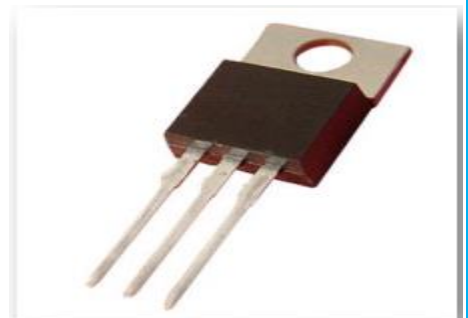


The first Generation computers used vacuum tubes for circuitry and magnetic drums for memory, and were often enormous, taking up entire rooms. • They were very expensive to operate and in addition to using a great deal of electricity, generated a lot of heat, which was often the cause of malfunctions.



Vacuum tube

The Second Generation • Transistors replaced vacuum tubes and ushered in the second generation of computers. • One transistor replaced the equivalent of 40 vacuum tubes. • Allowing computers to become smaller, faster, cheaper, more energy-efficient and more reliable. • Still generated a great deal of heat that can damage the computer.



Transistor

The Second Generation • Second-generation computers moved from cryptic binary machine language to symbolic, or assembly, languages, which allowed programmers to specify instructions in words. • Second-generation computers still relied on punched cards for input and printouts for output. • These were also the first computers that stored their instructions in their memory, which moved from a magnetic drum to magnetic core technology.

The Third Generation • The development of the integrated circuit was the hallmark of the third generation of computers. • Transistors were miniaturized and placed on silicon chips, called semiconductors, which drastically increased the speed and efficiency of computers. • Much smaller and cheaper compare to the second generation computers. • It could carry out instructions in billionths of a second.

The Third Generation • Users interacted with third generation computers through keyboards and monitors and interfaced with an operating system, which allowed the device to run many different applications at one time with a central program that monitored the memory. • Computers for the first time became accessible to a mass audience because they were smaller and cheaper than their predecessors.



Integrated Circuit

The Fourth Generation • The microprocessor brought the fourth generation of computers, as thousands of integrated circuits were built onto a single silicon chip. • As these small computers became more powerful, they could be linked together to form networks, which eventually led to the development of the Internet. • Fourth generation computers also saw the development of GUIs, the mouse and handheld devices.



Microprocessor

The Fifth Generation • Based on Artificial Intelligence (AI). • Still in development. • The use of parallel processing and superconductors is helping to make artificial intelligence a reality. • The goal is to develop devices that respond to natural language input and are capable of learning and self-organization. • There are some applications, such as voice recognition, that are being used today.



Analog and digital computer

Digital computer is that computer, which performs and accepts the converted binary number data. Today most of the computers are digital computers. It is basically an electronic based computer. Rather than continuous its input functions works discretely. Input can be in form of letters, numbers written and represented in special binary coded languages. Microcomputers, personal computers, network servers, super computers and multi-processor computers are kinds of digital computer. It uses two binary code or digits 0 and 1, which stands for no and yes, false and true, left and right. All instructions given to computer are performed through these two digits.



Analog computer is that computer, which performs the functions continuously irrespective of variations in input, which can be in form of fluctuation in voltage or temperature, electrical or mechanical parts. Oscilloscopes, thermostat and thermometer are examples of analog computer. In start analog computer was used to measure the electrical signal, current, frequency of signal and voltage, resistance of capacitor, etc. Working with analog computer is not so easy. Number of electrical and mechanical peripheral and supporting devices are required for it to function properly.

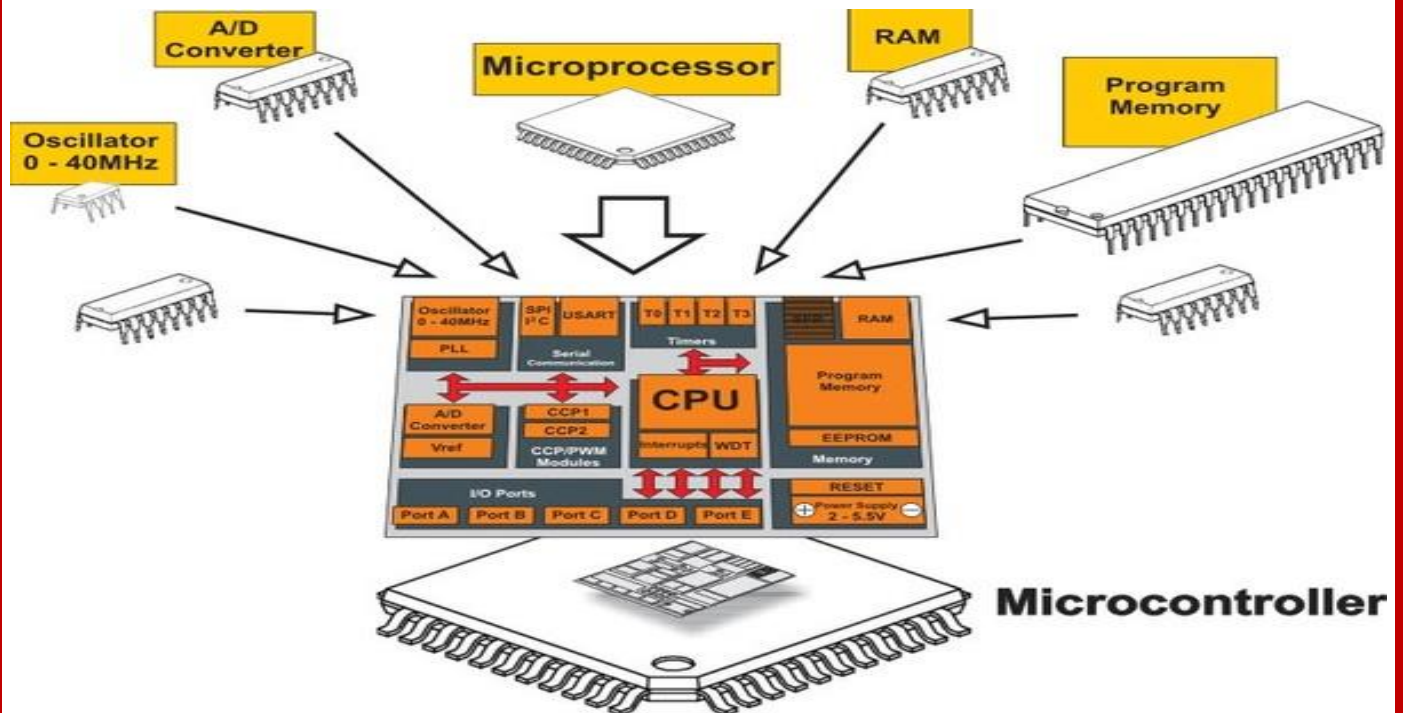


Microprocessor, microcomputer, microcontroller

Microcontroller and Microprocessors Are Integrated Circuits with several digital circuits inside them. It's hard to decide about any IC just by looking if it's a Microcontroller or Microprocessor, and often they are mixed together, because they both can be programmed in the similar way. One needs to check out their specifications in order to distinguish between.

Microcontroller: They are a whole complete system in themselves (*maybe sometimes specific Operating System too*). They consist of Processing Unit, RAM, ROM, other external peripherals. They generally have Harvard Architecture. The processing speed is comparatively slow. The addresses in programming are placed outside the IC. Eg: Arduino, 8051.

Microprocessor: They only consist of the Processing Unit. They *don't* have peripherals included in them. They generally have Von Neumann Architecture. The processing speed is comparatively faster. The addresses in programming have their own space. Eg: Raspberry pi.



Microprocessor is used in applications where *task is not predefined* or where *intensive processing* is required while Microcontroller is used for *specific propose*.

microprocessor chip contain only CPU(central processing unit),all other elements like memory are connected to it while in Microcontroller all elements including CPU are in one chip.

A microcomputer is a small, relatively inexpensive computer with a microprocessor as its central processing unit (CPU). It includes a microprocessor, memory, and minimal input/output (I/O) circuitry mounted on a single printed circuit board. Microcomputers became popular in the 1970s and 1980s with the advent of increasingly powerful microprocessors.

The predecessors to these computers, mainframes and minicomputers, were comparatively much larger and more expensive (though indeed present-day mainframes such as the IBM System z machines use one or more custom microprocessors as their CPUs).

Many microcomputers (when equipped with a keyboard and screen for input and output) are also personal computers (in the generic sense).

Stored program concept and von-Neumann's architecture

Stored-program concept:

Storage of instructions in computer [memory](#) to enable it to perform a variety of tasks in sequence or intermittently. The idea was introduced in the late 1940s by [John von Neumann](#), who proposed that a program be electronically stored in binary-number format in a memory device so that instructions could be modified by the computer as determined by intermediate computational results. Other engineers, notably [John W. Mauchly](#) and [J. Presper Eckert](#), contributed to this idea, which enabled [digital computers](#) to become much more flexible and powerful. Nevertheless, engineers in England built the first stored-program computer, the [Manchester Mark I](#), shortly before the Americans built [EDVAC](#), both operational in 1949.

Von Neumann Architecture:

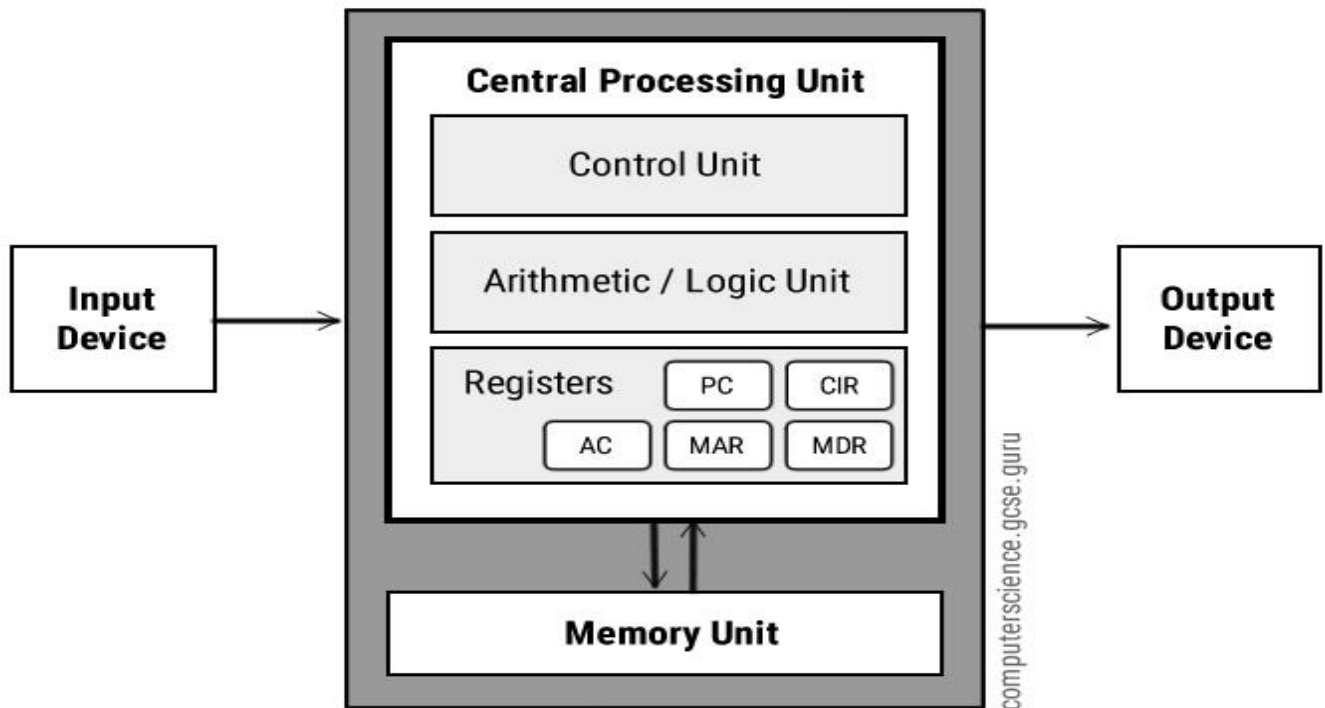
John von Neumann, original name **János Neumann**, (born December 28, 1903, Budapest, Hungary—died February 8, 1957, Washington, [D.C.](#), U.S.), Hungarian-born American mathematician. As an adult, he appended *von* to his surname; the hereditary title had been granted his father in 1913. Von Neumann grew from child prodigy to one of the world's foremost mathematicians by his mid-twenties. Important work in [set theory](#) inaugurated a career that touched nearly every major branch of mathematics. Von Neumann's gift for applied [mathematics](#) took his work in directions that influenced [quantum theory](#), [automata theory](#), [economics](#), and defense planning. Von Neumann pioneered [game theory](#) and, along with [Alan Turing](#) and [Claude Shannon](#), was one of the [conceptual](#) inventors of the stored-program digital [computer](#).

Von Neumann architecture was first published by John von Neumann in 1945. His computer architecture design consists of a Control Unit, [Arithmetic and Logic Unit](#) (ALU), Memory Unit, [Registers](#) and Inputs/Outputs.

Von Neumann architecture is based on **the stored-program computer concept**, where instruction data and program data are stored in the same memory. This design is still used in most computers produced today.

Central Processing Unit (CPU): The [Central Processing Unit](#) (CPU) is the electronic circuit responsible for executing the instructions of a computer program.

It is sometimes referred to as the microprocessor or processor. The CPU contains the ALU, CU and a variety of registers.



Registers: Registers are high speed storage areas in the CPU. All data must be stored in a register before it can be processed.

MAR Memory Address Register: Holds the memory location of data that needs to be accessed

MDR Memory Data Register: Holds data that is being transferred to or from memory

AC Accumulator: Where intermediate arithmetic and logic results are stored

PC Program Counter: Contains the address of the next instruction to be executed

CIR Current Instruction Register: Contains the current instruction during processing

Arithmetic and Logic Unit (ALU) allows arithmetic (add, subtract etc) and logic (AND, OR, NOT etc) operations to be carried out.

Control unit controls the operation of the computer's ALU, memory and input/output [devices](#), telling them how to respond to the program instructions it has just read and interpreted from the memory unit. The control unit also provides the timing and control signals required by other computer components.

Buses are the means by which data is transmitted from one part of a computer to another, connecting all major internal components to the CPU and memory. A standard CPU system bus is comprised of a [control bus](#), [data bus](#) and [address bus](#).

Address Bus Carries the addresses of data (but not the data) between the processor and memory. **Data Bus** Carries data between the processor, the memory unit and the input/output devices. **Control Bus** Carries control signals/commands from the CPU (and status signals from other devices) in order to control and coordinate all the activities within the computer.

Memory Unit : The memory unit consists of [RAM](#), sometimes referred to as primary or main memory. Unlike a hard drive (secondary memory), this memory is fast and also directly accessible by the CPU.

RAM is split into partitions. Each partition consists of an address and its contents (both in binary form).

The address will uniquely identify every location in the memory.

Loading data from permanent memory (hard drive), into the faster and directly accessible temporary memory (RAM), allows the CPU to operate much quicker.

General architecture of a microcomputer system showing control buses

or

The concept and architecture of a microcomputer

A microcomputer is a computer built on the basis of a microprocessor i.e. a processor implemented as an integrated circuit. Since all processors are now produced in the form of integrated circuits, we can say that all computers are microcomputers. The general method for constructing microcomputers consists in connecting to the microprocessor busses additional sub-systems such as memories and peripheral device controllers (input/output units).

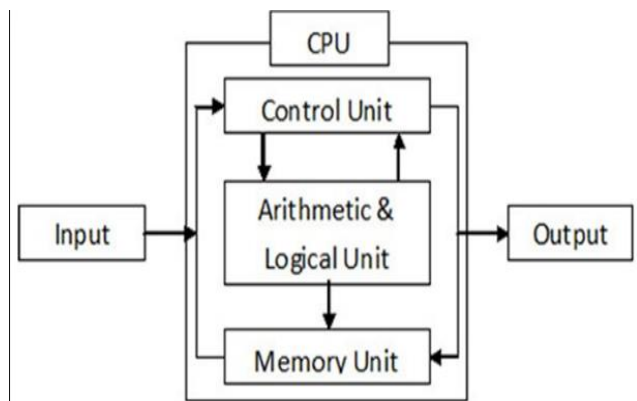
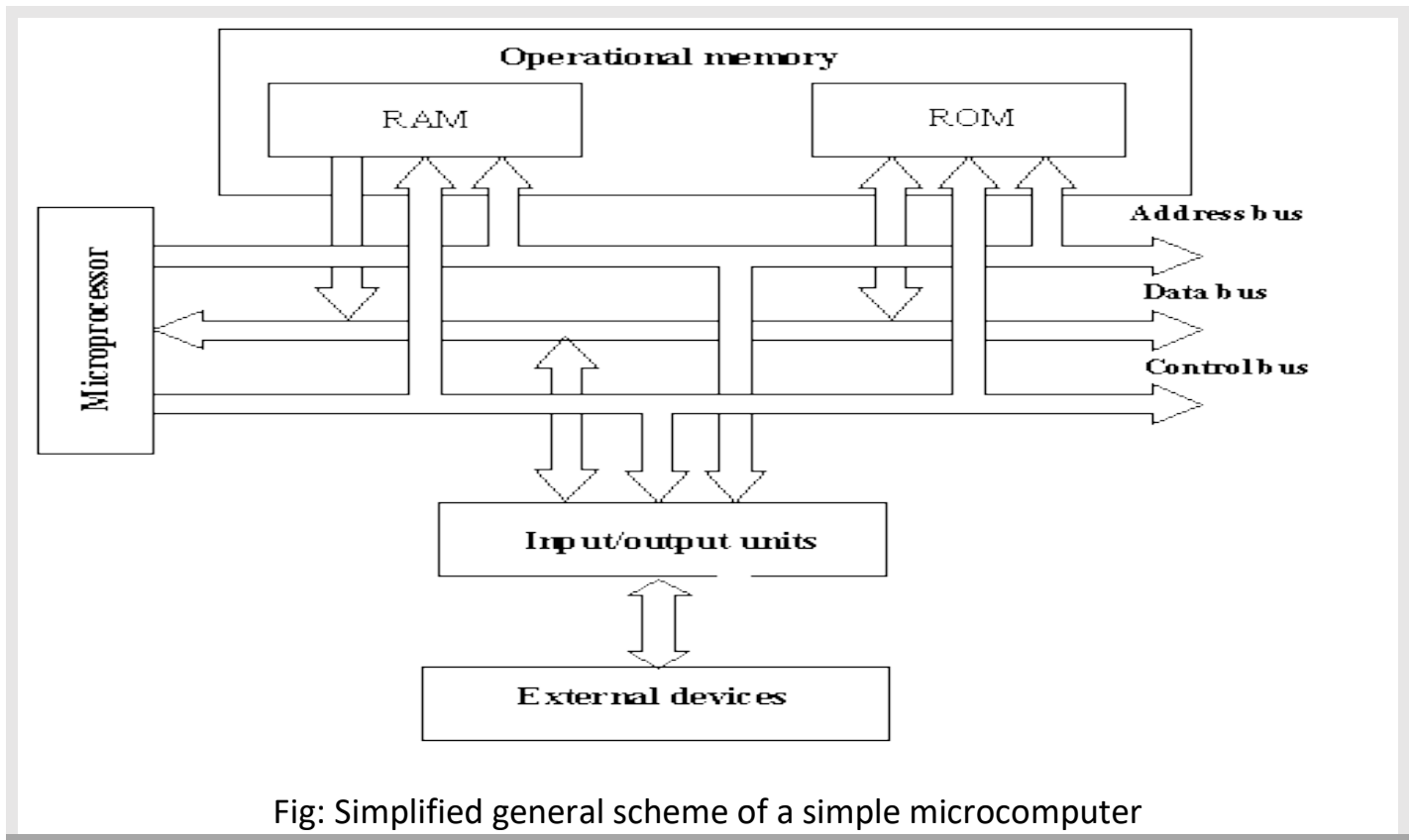


Fig. Block Diagram of Computer

The basic block diagram of a simple microcomputer is shown in the figure below. We can see there a microprocessor with three its busses going out: data bus, address bus and control bus. To these busses, the following devices are connected: operational memory composed of RAM (Random Access Memory) and ROM (Read Only Memory) memories, as well as input/output units to which peripheral devices are connected.



History of x86 microprocessors

(By Timeline Basis)

Here's a peek at the events and technologies that led to the development of Intel's x86 architecture, plus milestones in its 30-year reign.

1947: The transistor is invented at Bell Labs.

1965: Gordon Moore at Fairchild Semiconductor observes in an article for *Electronics* magazine that the number of transistors on a semiconductor chip doubles every year (**Next Semester in Operating System**). For microprocessors, it will double about every two years for more than three decades.



Intel co-founder Gordon Moore

1968: Moore, Robert Noyce and Andy Grove found Intel Corp. to pursue the business of "**Integrated Electronics**."

1969: Intel announces its first product, the world's first metal oxide semiconductor (MOS) static RAM, the 1101. It signals the end of magnetic core memory.

1971: Intel launches the world's first microprocessor, the **4-bit 4004**, designed by Federico Faggin.

The 2,000-transistor chip is made for a Japanese calculator, but a far sighted Intel ad calls it "a micro programmable computer on a chip."



The Intel 4004

1972: Intel announces the **8-bit 8008** processors. Teenagers Bill Gates and Paul Allen try to develop a programming language for the chip, but it is not powerful enough.



The Intel 8080 (GNU FDL 1.2)

1974: Intel introduces the **8-bit 8080 processors**, with 4,500 transistors and 10 times the performance of its predecessor.

1975: The 8080 chip finds its first PC application in the Altair 8800, launching the **PC revolution**. Gates and Allen succeed in developing the Altair Basic language, which will later become Microsoft Basic, for the 8080.

1976: **Intel 8085** is an 8-bit microprocessor. It is a software-binary compatible with the more-famous Intel 8080 with only two minor instructions added to support its added interrupt and serial input/output features.



1976: The x86 architecture suffers a setback when **Steve Jobs and Steve Wozniak** introduce the Apple II computer using the 8-bit 6502 processors from MOS Technology. PC maker Commodore also uses the Intel competitor's chip.

1978: Intel introduces the **16-bit 8086** microprocessors. It will become an industry standard.



The Intel 8086 (GNU FDL 1.2)

1979: Intel introduces a lower-cost version of the 8086, the 8088, with an 8-bit bus.

1980: Intel introduces the **8087 math co-processor**.

1981: IBM picks the Intel 8088 to power its PC. An Intel executive would later call it "**the biggest win ever for Intel.**"

1982: IBM signs Advanced Micro Devices as second source to Intel for 8086 and 8088 microprocessors.

1982: Intel introduces the 16-bit 80286 processors with 134,000 transistors.



The IBM PC (GNU FDL 1.2)

1984: IBM develops its second-generation PC, the 80286-based **PC-AT**. The PC-AT running MS-DOS will become the de facto PC standard for almost 10 years.

1985: Intel exits the dynamic RAM business to focus on microprocessors, and it brings out the 80386 processor, a 32-bit chip with 275,000 transistors and the ability to run multiple programs at once.

1986: Compaq Computer leapfrogs IBM with the introduction of an 80386-based PC.

1987: VIA Technologies is founded in Fremont, Calif., to sell x86 core logic chip sets.

1989: The 80486 is launched, with 1.2 million transistors and a built-in math co-processor. Intel predicts the development of multicore processor chips some time after 2000.



The Intel 80386 (GNU FDL 1.2)

Late 1980s: The complex instruction set computing (CISC) architecture of the x86 comes under fire from the rival reduced instruction set computing (RISC) architectures of the Sun Sparc, the IBM/Apple/Motorola PowerPC and the MIPS processors. Intel responds with its own RISC processor, the i860.



The AMD Am486, an Intel 486 competitor (GNU FDL 1.2)

1990: Compaq introduces the industry's first PC servers, running the 80486.

1993: The 3.1 million transistor, 66-MHz Pentium processor with superscalar technology is introduced.

1994: AMD and Compaq form an alliance to power Compaq computers with Am486 microprocessors.

1995: The Pentium Pro, a RISC slayer, debuts with radical new features that allow instructions to be anticipated and executed out of order. That, plus an extremely fast on-chip cache and dual independent buses, enable big performance gains in some applications.



Intel's Pentium Pro (GNU FDL 1.2)

1997: Intel launches its 64-bit Epic processor technology. It also introduces the MMX Pentium for digital signal processor applications, including graphics, audio and voice processing.

1998: Intel introduces the low-end Celeron processor.

1999: VIA acquires Cyrix Corp. and Centaur Technology, makers of x86 processors and x87 co-processors.

2000: The Pentium 4 debuts with 42 million transistors.

2003: AMD introduces the x86-64, a 64-bit superset of the x86 instruction set.

2004: AMD demonstrates an x86 dual-core processor chip.

2005: Intel ships its first dual-core processor chip.

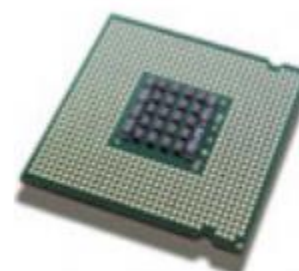
2005: Apple announces it will transition its Macintosh computers from PowerPCs made by Freescale (formerly Motorola) and IBM to Intel's x86 family of processors.

2005: AMD files antitrust litigation charging that Intel abuses "monopoly" to exclude and limit competition. (The case is still pending in 2008.)

2006: Dell Inc. announces it will offer AMD processor-based systems.



AMD64, a rebranding of x86-64



Intel's first dual-core chip, the Pentium D

NAME	YEAR	TRANSISTORS	DATA WIDTH	CLOCK SPEED
8080	1974	6,000	8 bits	2 MHz
8085	1976	6,500	8 bits	5 MHz
8086	1978	29,000	16 bits	5 MHz
8088	1979	29,000	8 bits	5 MHz
80286	1982	134,000	16 bits	6 MHz
80386	1985	275,000	32 bits	16 MHz
80486	1989	1,200,000	32 bits	25 MHz
PENTIUM	1993	3,100,000	32/64 bits	60 MHz
PENTIUM II	1997	7,500,000	64 bits	233 MHz
PENTIUM III	1999	9,500,000	64 bits	450 MHz
PENTIUM IV	2000	42,000,000	64 bits	1.5 GHz

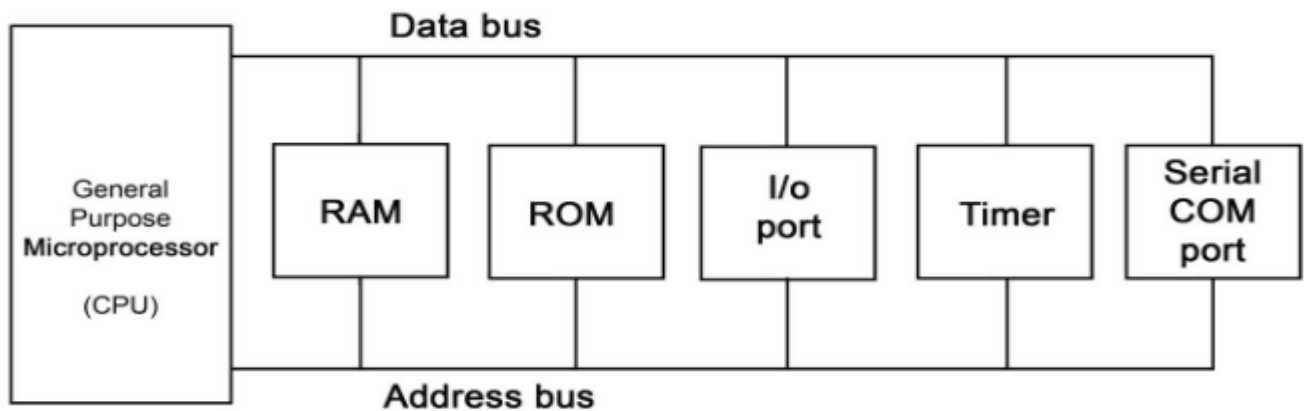
Evolution of Microprocessors

Block diagram of a typical microprocessor and microcontroller

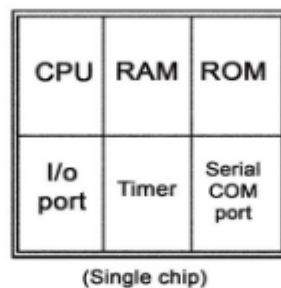
Microcontroller contains : CPU, RAM, ROM, I/O ports, and, counter, timers etc is on a single chip.

Microprocessor contains: CPU stands alone, RAM, ROM, I/O ports, and, counter, timers. etc.

(a). GENERAL PURPOSE MICROPROCESSOR SYSTEM



(b). MICROCONTROLLER



Your Desk

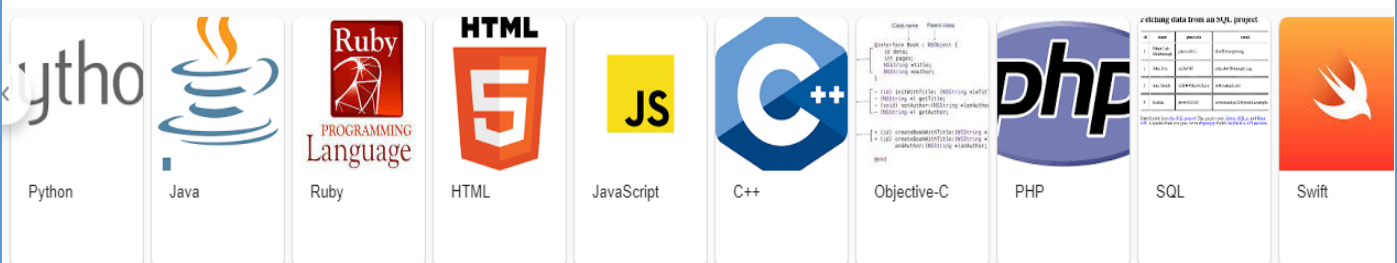
Programming languages

Compiler: It's a computer program(s) that transforms source code written in a programming language into machine language that is the target language which usually has a binary form known as object code.

Interpreter: It translates high level instructions into an intermediate form, it translates the code into the intermediate form line by line and carries out specific actions.

Assembler: It is a program that takes basic computer instruction(s) and converts them into a pattern of bits that the computer's processor can use to perform its basic operations. The language used to program the assembler is called assembly language.

- Compiler Takes **Entire** program as input whereas Interpreter Takes **Single** instruction as input.
- Intermediate Object Code is **Generated** in case of compiler whereas in case of interpreter **No** Intermediate Object Code is **Generated**.
- **Memory Requirement** is **More** (Since Object Code is Generated) in case of compiler whereas **Memory Requirement** is **Less** in case of interpreter.
- **Errors** are displayed after **entire program** is checked in case of compiler. Hence debugging is comparatively hard. In case of an interpreter, **Errors** are displayed for **every instruction** interpreted (if any). An interpreter continues translating the program until the first error is met, in which case it stops. Hence debugging is easy.



High Level Languages: are written in a form that is close to our human language, enabling to programmer to just focus on the problem being solved.

No particular knowledge of the hardware is needed as high level languages create programs that are portable and not tied to a particular computer or microchip.

These programmer friendly languages are called 'high level' as they are far removed from the code instructions understood by the computer.

Examples include: C++, Java, Pascal, Python, Visual Basic.

Advantages

- Easier to modify as it uses English like statements
- Easier/faster to write code as it uses English like statements
- Easier to debug during development due to English like statements
- Portable code – not designed to run on just one type of machine

Low level languages are used to write programs that relate to the specific architecture and hardware of a particular type of computer.

They are closer to the native language of a computer (binary), making them harder for programmers to understand.

Low level refers to:

- [Assembly Language](#)
- Machine Code

Assembly Language: Few programmers write programs in low level assembly language, but it is still used for developing code for specialist hardware, such as device drivers.

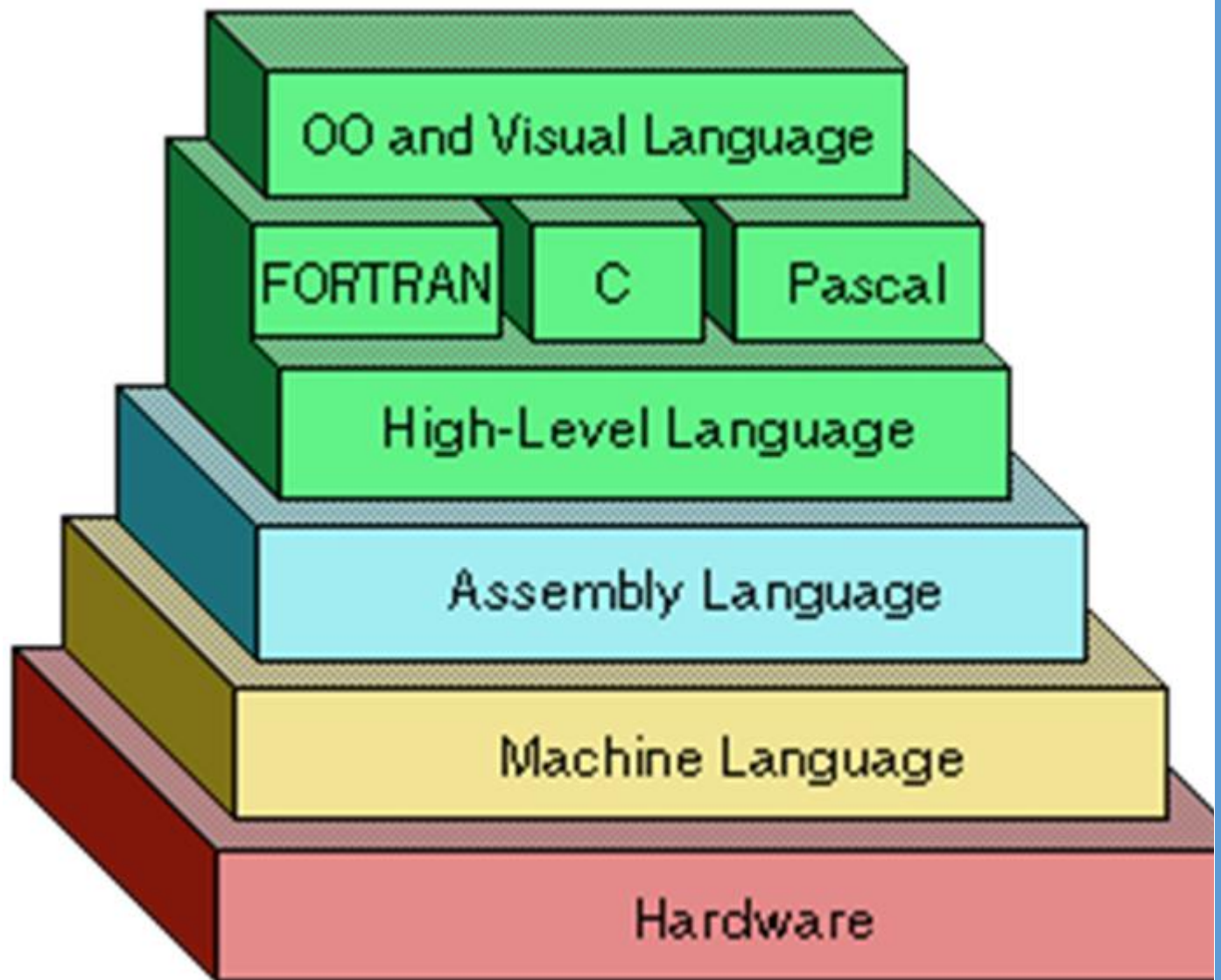
It is easy distinguishable from a high level language as it contains few recognizable human words but plenty of mnemonic code.

Advantages

- Can make use of special hardware or special machine-dependent instructions (e.g. on the specific chip)
- Translated program requires less memory
- Write code that can be executed faster

- Total control over the code
- Can work directly on memory locations

Machine Code: Programmers rarely write in machine code (binary) as it is difficult to understand.



Computer Organization

|

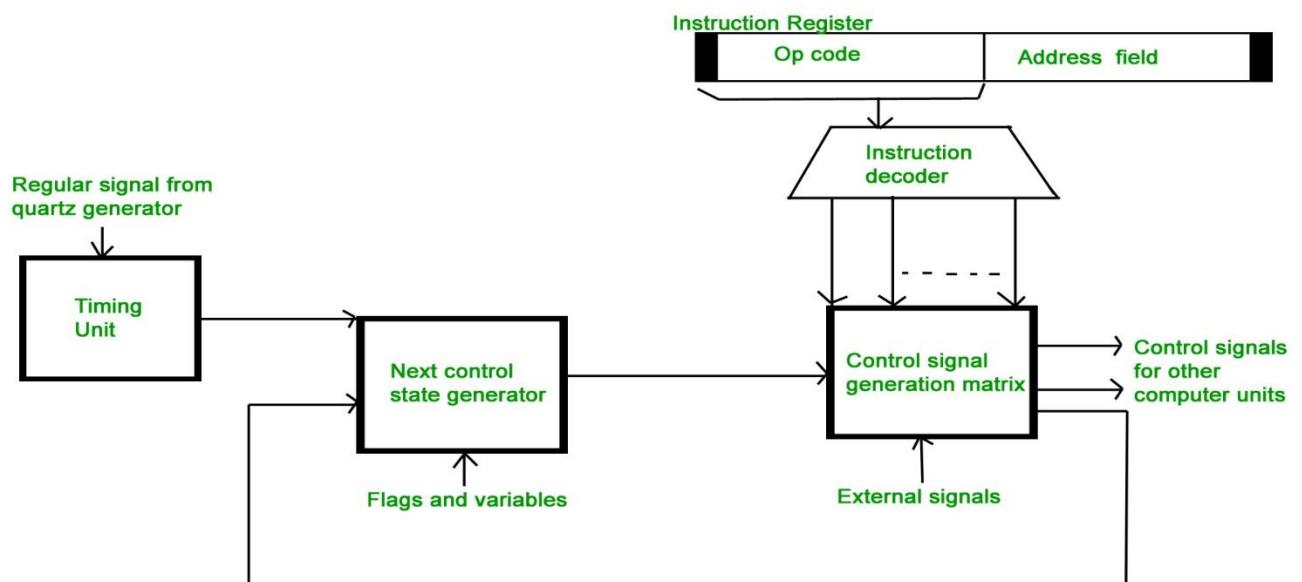
Hardwired v/s Micro-Programmed Control Unit

To execute an instruction, the control unit of the CPU must generate the required control signal in the proper sequence. There are two approaches used for generating the control signals in proper sequence as Hardwired Control unit and Micro-programmed control unit.

Hardwired Control Unit –

The control hardware can be viewed as a state machine that changes from one state to another in every clock cycle, depending on the contents of the instruction register, the condition codes and the external inputs. The outputs of the state machine are the control signals. The sequence of the operation carried out by this machine is determined by the wiring of the logic elements and hence named as “hardwired”.

- Fixed logic circuits that correspond directly to the Boolean expressions are used to generate the control signals.
- Hardwired control is faster than micro-programmed control.
- A controller that uses this approach can operate at high speed.

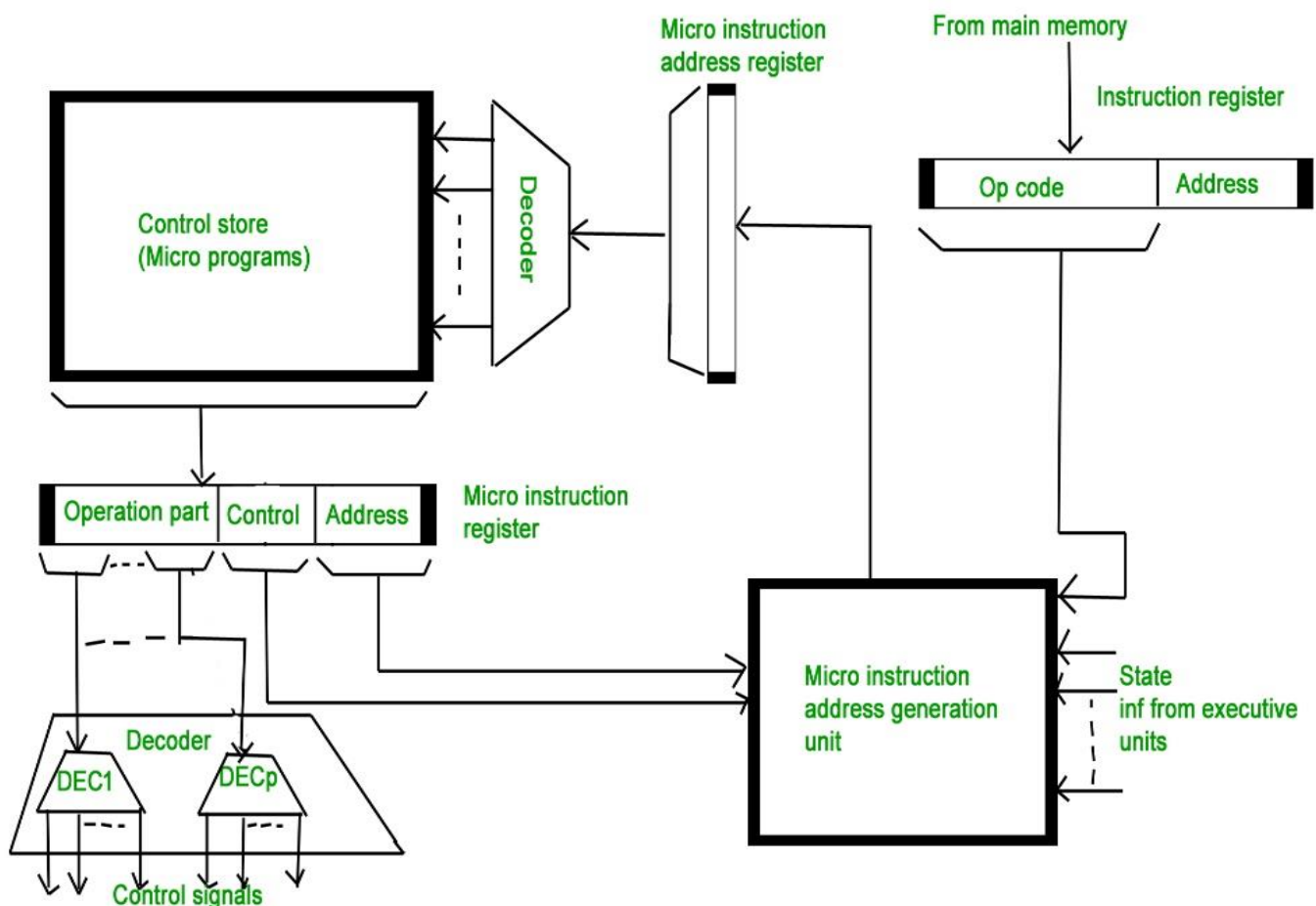


Micro-programmed Control Unit –

- The control signals associated with operations are stored in special memory units inaccessible by the programmer as Control Words.
- Control signals are generated by a program are similar to machine language programs.
- Micro-programmed control unit is slower in speed because of the time it takes to fetch microinstructions from the control memory.

Some Important Terms –

1. **Control Word** : A control word is a word whose individual bits represent various control signals.
2. **Micro-routine** : A sequence of control words corresponding to the control sequence of a machine instruction constitutes the micro-routine for that instruction.
3. **Micro-instruction** : Individual control words in this micro-routine are referred to as microinstructions.
4. **Micro-program** : A sequence of micro-instructions is called a micro-program, which is stored in a ROM or RAM called a Control Memory (CM).
5. **Control Store** : the micro-routines for all instructions in the instruction set of a computer are stored in a special memory called the Control Store.



Types of Micro-programmed Control Unit –

Based on the type of Control Word stored in the Control Memory (CM), it is classified into two types :

1. Horizontal Micro-programmed control Unit :

The control signals are represented in the decoded binary format that is 1 bit/CS.

Example: If 53 Control signals are present in the processor than 53 bits are required. More than 1 control signal can be enabled at a time.

- It supports longer control word.
- It is used in parallel processing applications.
- It allows higher degree of parallelism. If degree is n , n CS are enabled at a time.
- It requires no additional hardware(decoders). It means it is faster than Vertical Microprogrammed.

2. Vertical Micro-programmed control Unit :

The control signals are represented in the encoded binary format. For N control signals- $\log_2(N)$ bits are required.

- It supports shorter control words.
- It supports easy implementation of new control signals therefore it is more flexible.
- It allows low degree of parallelism i.e., degree of parallelism is either 0 or 1.
- Requires an additional hardware (decoders) to generate control signals, it implies it is slower than horizontal microprogrammed.

List of Processor Manufacturing Companies

- 1 Altera
- 2 AMD
- 3 Apollo
- 4 ARM
- 5 Atmel
- 6 AT&T
- 7 Bell Labs
- 8 BLX IC Design Corporation
- 9 Centaur Technology/IDT
- 10 Cyrix
- 11 Data General
- 12 Digital Equipment Corporation
- 13 Emotion Engine by Sony & Toshiba
- 14 Elbrus
- 15 Electronic Arrays
- 16 EnSilica
- 17 Fairchild Semiconductor
- 18 Freescale Semiconductor (formerly Motorola)
- 19 Fujitsu
- 20 Garrett AiResearch
- 21 Google
- 22 Harris Semiconductor
- 23 Hewlett-Packard
- 24 Hitachi
- 25 Inmos
- 26 IBM
- 26.1 POWER
- 26.2 PowerPC-AS
- 26.3 z/Architecture

AMD [\[edit \]](#)

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- [List of AMD K5 microprocessors](#)
- [List of AMD Athlon microprocessors](#)
- [List of AMD Athlon 64 microprocessors](#)
- [List of AMD Athlon XP microprocessors](#)
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- [List of AMD Opteron microprocessors](#)
- [List of AMD Sempron microprocessors](#)
- [List of AMD Turion microprocessors](#)
- [List of AMD Athlon X2 microprocessors](#)
- [List of AMD Phenom microprocessors](#)
- [List of AMD FX microprocessors](#)
- [List of AMD Ryzen microprocessors](#)

27	Intel
28	Intersil
29	ISRO
30	Lattice Semiconductor
31	MIPS Technologies
32	MOS Technology
33	National Semiconductor
34	NEC
35	NVIDIA
36	NXP (formerly Philips Semiconductors)
37	OpenCores
38	Oracle Corporation (formerly Sun Microsystems)
39	RCA
40	Renesas Electronics
41	RISC-V Foundation
42	Sunway
43	Texas Instruments
44	Toshiba
45	VIA
46	Western Design Center
47	Western Digital
48	Western Electric
49	Xilinx
50	XMOS
51	Zilog

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 - [List of Intel Core i3 microprocessors](#)
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- [List of Intel Celeron microprocessors](#)
- [List of Intel Atom microprocessors](#)

Introduction to Simple as Possible (SAP) computers

The Simple-As-Possible (SAP)-1 computer is a very basic model of a microprocessor explained by Albert Paul Malvino. The SAP-1 design contains the basic necessities for a functional Microprocessor. Its primary purpose is to develop a basic understanding of how a microprocessor works, interacts with memory and other parts of the system like input and output.

SAP 1:

- W bus – A single 8-bit bus for address and data transfer.
- 16 Bytes memory (RAM).
- registers are accumulator and B-register each of 8 bits.
- Program counter – initializes from 0000 to 1111 during program execution.
- Memory Address Register (MAR) to store memory addresses.
- Adder/ Subtracted for addition and subtraction instructions.
- A Control Unit
- A Simple Output.
- 6 machine state reserved for each instruction
- The instruction format of SAP-1 Computer is (XXXX) (XXXX)

Differences between SAP-1 and SAP-2 Architecture

SAP-1	SAP-2
It has 8-bit bus.	It has 16-bit bus.
PC is 4-bit.	PC is 16-bit.
It does not have hexadecimal keyboard encoder.	It has hexadecimal keyboard encoder.
It has single input.	It has two input ports.
MAR receives 4-bit address from PC.	MAR receives 16-bit address from PC.
It does not have ROM.	It has 2 KB ROM.
It has 16 Byte memory.	It has 62 KB memory.
It does not have MDR.	It has MDR.
It has only adder/subtractor.	It has ALU.

It does not have flag.	It has 2 flags.
It does not have temporary register.	It has temporary register.
It has single register (B).	It has 2 registers (B and C).
It has single output port.	It has 2 output ports.
It has 5 instruction sets.	It has 42 instruction sets.

SAP-3

- architectural differences with SAP-1, SAP-2
- registers and move instructions
- arithmetic instructions and carry flag
- multi-precision addition and subtraction
- rotate and compare
- arithmetic, logic immediate instructions
- jump instructions
- 16-bit register pairing and 16-bit load, arithmetic
- indirect instructions

