Computer Organization & Architecture

Introduction

A computer is a programmable machine. The two principal characteristics of a computer are:

a. It responds to a specific set of **instructions** in a well-defined manner
b. It can **execute** a prerecorded list of instructions ie **a program**

In **computer** engineering, **computer architecture** is a set of rules and methods that describe the functionality, organization, and implementation of **computer systems**. Some definitions of **architecture** define it as describing the capabilities and programming model of a **computer** but not a particular implementation.

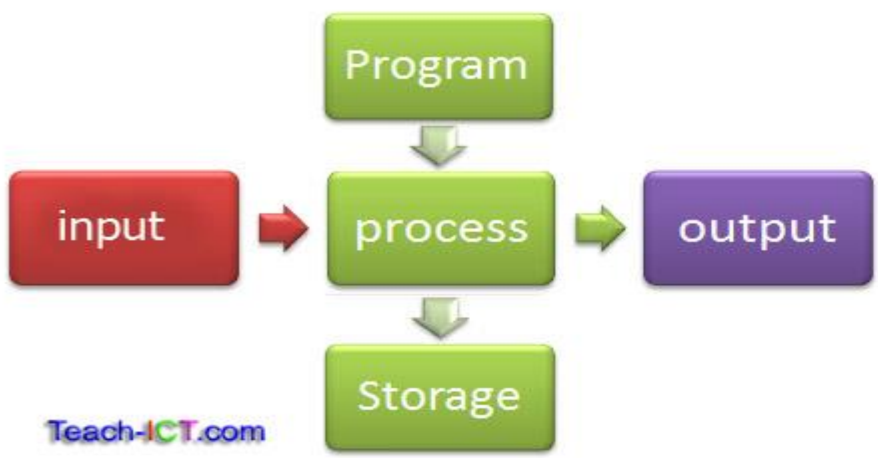
Computer organization is concerned with the structure and behavior of a computer system as seen by the user.

Computer system

Computer system is one that is able to take a set of inputs, process them and create a set of outputs. This is done by a combination of hardware and software.

It is a combination of different components working together towards a common goal.

The diagram below shows you the idea of a computer system in its most basic form



Characteristics of Computer System:

A computer system is better than human beings in a way that it possesses the following capabilities:

(i) Speed

Speed is the amount of time taken by the computer in accomplishing a task of an operation. The time taken by a computer to perform a particular task is far less than that taken by than a human being. Different computers are classified on the basis of their speed by comparing their MIPS (Million Instructions Per Second).

(ii) Accuracy

Accuracy refers to the degree of correctness and exactness of operations performed by a computer. In the absence of bad programming, computers do not commit errors and are capable of handling complex instructions accurately. If the data fed into a computer is not error free, it is likely to produce inaccurate results.

(iii) Reliability

Computer systems are non-respondent to human factors like fatigue, tiredness or boredom. Therefore, they are more likely to work repeatedly and efficiently. In case of any failure in a computer system, there are provisions for immediate backup of information and programs.

(iv) Versatility

Computers are capable of performing all levels of tasks- simple or complex. Therefore, they can be used in any area-science, technology, business, finance, accounts, communications and so on.

(v) Storage

It refers to the capacity of a computer to store data and programs. Storage is done in storage media such as CDs, Floppies, DVDs, RAM (Random Access Memory), ROM (Read Only Memory).

Limitations of a Computer System

Although a computer is far better in performance than a human being, it fails in certain ways as follows:

(i) Computers can’t Think

Computers cannot think and they can’t do any job unless they are first programmed with specific instructions for the same. They work as per stored instructions. Algorithms are designed by humans to make a computer perform a special task. This is also called artificial intelligence.

(ii) Computers can’t Decide

Computers are incapable of decision making as they do not possess the essential elements necessary to take a decision i.e. knowledge, information, wisdom, intelligence and the ability to judge.

(iii) Computers can’t Express their Ideas

In any type of research ideas plays a vital role. In this context, computers can’t express their ideas.

(iv) Computers can’t Implement

Though computers are helpful in storage of data and can contain the contents of encyclopedias even, but only humans can decide and implement the policies.

Types of computer systems

a. **Abstract and physical systems**

An abstract or conceptual system is an orderly arrangement of interdependent ideas or constructs, which may or may not have any counterpart in the real world.

On the other hand, physical systems are generally concrete operational systems made up of people, materials, machines, energy and other physical things; Physical systems are more than conceptual constructs.

b. **Deterministic and Probabilistic Systems**

A deterministic system is one in which the occurrence of all events is known with certainty.

A probabilistic system is one in which the occurrence of events cannot be perfectly predicted. Though the behavior of such a system can be described in terms of probability, a certain degree of error is always attached to the prediction of the behavior of the system.

c. **Open and Closed Systems**

An open system is one that interacts with its environment and thus exchanges information, material, or energy with the environment, including random and undefined inputs. Open systems are adaptive in nature, as they tend to react with the environment in such a way, so as to favor their continued existence. Such systems are 'self organizing', in the sense that they change their organization in response to changing conditions.

A closed system is one, which does not interact with its environment. Such systems in business world, are rare, but relatively closed systems are common. Thus, the systems that are relatively isolated from the environment but not completely closed, are termed closed system.

d. User Machine Systems

Most of the physical systems are user-machine (or human –machines) systems It is difficult to think of a system composed only of people who do not utilize equipment of some kind to achieve their goals. In user-machine systems, both, i.e. human as well as machine perform some activities in the accomplishment of a goal (e.g. decision-making). The machine elements (may be computer hardware and software) are relatively closed and deterministic, whereas the human elements of the system are open and probabilistic.

Classifications of Computer systems

Computer systems can be classified using very many aspects or characteristics. The most commonly used are:-

- Type of data used by the computer
- How the computer is used
- Size and complexity of the computer
- Function of the computer

i. Classification on the basis of Data Type

What is data?

Data are facts, as they are as collected from natural origin. When data is collected, it is then sorted out to remove the unwanted duplicated facts and facts that are not valid for the domain under consideration. Facts usually don't convey a lot of meaning and thus cannot be used to make decisions.

When data is processed, information is obtained. This information has meaning and can be used to make sound decisions.

Computers in general handle two types of data. These are digital and Analogue data. With these, computers are classified as digital computers or analogue computers.

Digital computers use data that is inform of digital signals which analogue computers use data which is the form of analogue signals.

a. **Analogue signal**

In analogue computers data is in the form of a current or voltage. The voltage or current is a continuous signal and varies with time. This is as shown in the figure 1 below

b. **Digital signal**

In digital computers data is in the form of discrete pulses. This is as shown in figure 1 below.

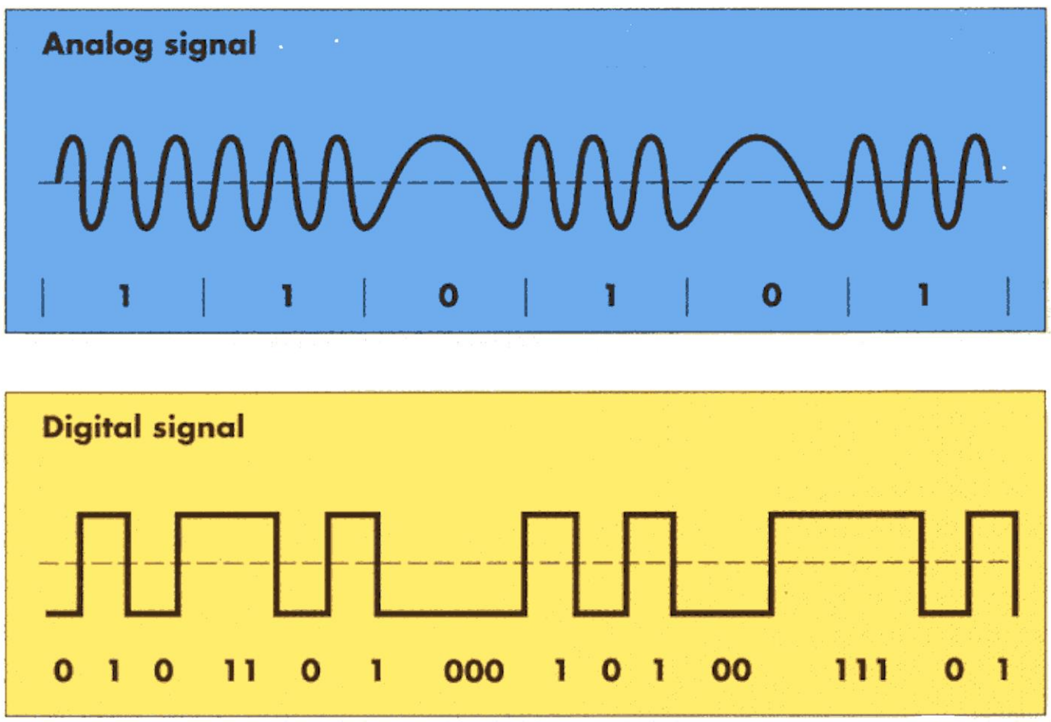


Figure 1

From figure 1 above, in the case of analogue signal where the signal is compressed, this is taken as a 1 and where it is not compressed this is taken as a 0

For the digital signal, where the digital signal is high – a pulse, this is taken to mean a 1 and where the digit is low – no pulse, this is taken as a 0.

Digital computers are very fast but analogue computers are slow in their operations.

ii. **Classification according to use**

Based on their use, computers are classified as special purpose or general purpose.

a. Special purpose computers

Special purpose implies that the computer is specially designed for one dedicated task. For example in a business tool, research tool, education, manufacturing industry process control, telecommunications, space exploration, weather forecasting, etc.

Such computers are like the servers and they require large and fast memory plus high computing power.

b. General purpose computer

General purpose computers are not committed to any special or dedicated work. They are used for any general work that includes home use, playing of games at home or office, surfing internet at home or in the office, chatting, e-mail access, teleworking, downloading of music and other stuff from the internet, etc.

Such computers include laptops, desktops or workstations.

Hard disk and memory capacities for such computers are not high.

iii. Classification according to size and complexity

Based on the size, computers are classified as

- Mainframes
- Minicomputers
- Microcomputers
- Personal Data Assistants

a. Main Frame Computer

This is a multi-user computer designed to meet the computing needs of a large organization

A Multi-user computer is one that can be used by several users at the same time.

The term main frame originally referred to the metal cabinet housing the CPU but in general sense refers to computers of the 1950s and 1960s

It used large number of dumb terminals for input/output and had a large number of peripherals attached.

A main frame can process a number of applications concurrently. This is known as multi-processing which aims at keeping the CPU as busy as possible.

This computer system was usually housed in special rooms. Special room implies that since the computer system generated a lot of heat during its operation room cooling or air conditioning equipment was a must. Since the operations were to be maintained throughout, power sourcing was a big issue. Power sources used for modern computer systems include the commercial AC power, the generator power (AC) and the Battery bank power source which is DC.

b. Mini Frame Computer

This is a scaled down mainframe designed to meet the computing needs of a small company or a department of a large organization.

Typically, it can handle up to 100 concurrent users supporting a number of concurrent applications through time sharing. This computer system does not require a special operating environment.

c. Microcomputer System

This appeared in the late 70s with the coming of the integrated circuits.

The size of the microcomputer is even very small compared to the minicomputer. The computer system is portable and multimedia; allowing integration of sound, video, graphics as well as text into software.

Nowadays microcomputer system refers to workstations, and personal computers. These are more powerful than the mainframe computers used those days.

d. Personal Data Assistants (PDAs)

These are very small, portable, pocket-sized computers.

Sometimes they use a pen as an input device and have software that can even translate the hand writing.

iv. Classification of computers based on functions

Computer systems are classified as:

- Stand Alone computers systems
- Centralized computer systems
- Distributed computer systems

a. Standalone computer system

The simplest in this class is a Personal computer. This is used by one person at a time. It has no shared resources.

b. Centralized computer system

Here all the Services, applications and shared resources are stored in one central location – the centralized computer system. Users in different locations have computers with no storage and no computing power. These user computers can connect (through Links) to the centralized computing system to access the resources they require. The centralized computing system allows many concurrent users to access many concurrent applications or services simultaneously.

c. **Distributed computer system**

The organization is similar to that of the centralized computing system. Instead of the centralized computing system, there is a central office with high computing power and fast computers. The computers at the user end also have some computing power and some storage. This is only enough to handle the users data processing at the location. Some resources are shared and these are available at the central office. This implies that each user has access to the computing power of the machine they are on but can obtain further computing power and facilities by connecting to other computers on the network or by connecting to the computer system in the central office.

History of Computers

Before 500 BC

Numbers did not exist. Twigs, knots, pebbles, fingers were the most convenient means of tracking quantities.

500BC

Babylonians made advances in accounting and devised the Abacus. This was a mechanical frame-work with rods with free-moving beads. This device operated by accepting data (quantities), a set of instructions (add or subtract) and in return provided an answer — it captured the essence of a computer. The abacus is an example of the earliest known computing device: a primitive calculator that possesses some sort of innate intelligence allowing it to translate instructions into meaningful answers.

400 BC

Arabs invented the decimal numbering system - the basic language of mathematics. With this, it became possible to learn the answers to more complex problems e.g. 150 + 50; without having to visualize 200 pebbles. . It also gave way to pre-computed answers in the form of lookup tables - the most trivial form of computational engineering. Lookup tables such as the ones used for multiplication can instantaneously provide answers at glance without any mental effort.

The model of the abacus integrated the knowledge of the decimal number system and evolved into a mechanical calculator.

In 1837, Charles Babbage designed the first general purpose computer called the Analytical Engine. His efforts earned him the title ”father of computing”. The analytical engine measured 10M wide by 30M long powered by a steam engine. It could accept not only data but program functions. Inputs would be fed via punched card. This design was not fully realized because of financial constraints.

During the mid-1800s, Thomas Alva Edison’s pioneering work in the field of electricity allowed it to be harnessed for practical use for the first time. With the control of electricity came the radio, the light bulb, wires and other invaluable electrical inventions.

With the invention of electricity, the beads of the abacus were replaced by bits in the modern computer. The creation of the bit marked a transition from the decimal system for humans (10 primary numbers from zero to nine) to a binary system for computers.

George Boole, a mathematician and philosopher, relied on binary arithmetic to advance his theories of logic, at the time still a branch of philosophy. The field would later evolve into Boolean algebra for managing and calculating the outcome of a number of bits interacting with each other. The simplest of Boolean logic might take the following form: a light switch toggles a light bulb — flipping the switch turns the light on if, and only if, it’s off, and vice versa.

In 1946, the US army built the ENIAC - Electronic Numerical Integrator And Computer. This was 30-tonne. The ENIAC was the first fully programmable machine capable of solving almost any mathematical problem. The ENIAC was capable of adding 5,000 numbers per second. It was powered by 18,000 vacuum tubes, 6,000 switches, around five million hand soldered joints and took three years to build. It was specifically programmed to calculate in a matter of hours the trajectory of artilleries to hit enemy targets.

While the input data could be stored on the ENIAC, the program to operate on the input had to be wired through plug board wiring. Programming it was cumbersome and each program required unplugging and re-plugging hundreds of wires.

Programming the ENIAC involved the use of switches and wire jampers or straps. This type of computer programming is called hardwire programming. It is cumbersome and each program requires unplugging and re-plugging many pieces of wires. It is also very difficult to realize complex programs using this method of programming. Faulting on a program is also difficult especially when the number of wires is enormous.

Shortly after the ENIAC, John von Neumann introduced the concept of a stored-program computer. Storing the program in the computer memory meant that the system of semi-permanent plug board wiring on the ENIAC could be deprecated. Bits would represent not only data, but also the programs themselves which used the data.

In the stored program computer, instead of using switches, and jampers or wire straps, to control computer functions, instructions were written to control the computer functions. These instructions were stored in the computer memory and constituted the computer software.

In 1956, a transistor was invented. Transistors are very small in contrast to vacuum tubes, require lesser power and are capable of switching states (1 to 0 and 0 to 1) much faster. Their beauty also lies in their composition: as solid-state semiconductors, they are built from material that has the ability to conduct electrical charge, like metal, or block it, like rubber. This resulted in drastic reduction in computer size, power consumption, and heat generation. It also led to portability of the computer and lesser need for external cooling in computing environment.

In 1970s, the Integrated Circuit was fabricated. An integrated circuit commonly referred to as an IC is a very small silicon chip in which several electronic components are fabricated. With the IC, the size of the computer reduced even further. The IC also enabled the computer to support multimedia applications.

Generations of Electronic Computers

a. **First Generation**

Vacuum Tubes were the main circuit components. The computers were too big in size, very expensive, cumbersome and only used in big organizations. Computers built of vacuum tubes also required an enormous amount of electrical power and generated an enormous amount of heat. As such, they required extensive air conditioning and ventilation systems.

A computer built of vacuum tubes required constant maintenance and replacement of burnt out tubes. Because of the size, power consumption, heat generation, short time between failures, and expense of computers built out of vacuum tubes these systems were not used at all in a communications environment.

b. **Second Generation**

This was ushered in by the invention of the transistor. A transistor is very small in size as compared to the vacuum tube. The transistor has the same functionality as the vacuum tube. When it was invented, it replaced the vacuum tube as the main component in the computer circuitry. The electronic component in the computer existed as discrete components. The size, power consumption, need for external cooling, of the computer reduced drastically.

c. **Third Generation**

This is marked with the invention of an integrated circuit. It was now possible to fabricate several electronic components on a very small silicon chip. Several transistors could now be fabricated together even resulting into further reduction in computer size. In this generation, only critical components of the computer such as the CPU were implemented on the chip. This normally was based on the small and medium scales of integrated circuits.

d. Fourth Generation

As the technology on ICs advanced, it was now possible to develop other advanced types of ICs such as the large scale integrated circuits and the very large scale integrated circuits. With these, it was possible to implement all the functions of the computer on one small silicon chip.

e. Fifth Generation

With further advancement in the integrated circuit(IC) technology, it is possible to fabricate very many electronic components s on one silicon chip to produce the ultra large scale integrated circuits. This is currently under research. Once this is realized, it will be possible to implement all the function of a computer together with those of the peripherals on a single silicon chip.

Chapter One: Number System

Data and information are represented using numerals and alphabets in computer systems. For this, various number systems are used. A number is a collection of digits or symbols. Each number system uses a set of unique digits or symbols. The symbols are used to express quantities as the basis for counting, determining order, comparing amounts, performing calculations, and representing value.

Most commonly used number systems are:

- Decimal Number systems
- Octal Number systems
- Binary Number system
- Hexadecimal Number system

Terminologies used with Number Systems

Bit

This is the short form for Binary Digit. A bit can be a 1 or a 0

Nibble

This is a group of 4 bits

Byte

This is a group of 8 bits. It is also called Octet or Word

Base

A number system is denoted as $\mathbf{X_n}$. n in this case is the base or the number system being used. X is a unique symbol within the allowed symbols in the number system n. The base is also called Radix.

a. Decimal Number System

This has ten unique symbols. The allowed symbols are 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9. Decimal number system is also called **Denary**.

The decimal number system is denoted as $\mathbf{X_{10}}$. X is a valid symbol within the symbols allowed for the decimal number system. It is also denoted as$\mathbf{X_{Ten}}$ or $\mathbf{X_{Dec}}$.

b. Octal Number System

This has eight unique symbols ranging from 0 to 7. It is denoted by $\mathbf{X_8}$ or$\mathbf{X_{Eight}}$ or$\mathbf{X_{Oct}}$

c. Binary Number System

This has only two unique symbols; 0 and 1. It is denoted by $\mathbf{X_2}$ or $\mathbf{X_{Two}}$ or $\mathbf{X_{Bin}}$.

d. Hexadecimal Number System

This has 16 unique symbols. The symbols comprise all the numeric and the first six alphabetic (CAPITAL letters) characters.

The symbols are: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, and F.

The number system is denoted as $\mathbf{X_{16}}$ or $\mathbf{X_{Sixteen}}$ or $\mathbf{X_{Hex}}$.

Note: For each of the number systems, the value of a digit depends on it position in the number.

Examples

1. 2134562_{10}

Position value increase from Right to Left in powers of 10

10^6	10^5	10^4	10^3	10^2	10^1	10^0
2	1	3	4	5	6	2

- The value of a digit depends on its magnitude

For example

Value of 1 = 1 x 10^5 = 100 000

Value of 3 = 3 x 10^4 = 30 000

Value of 6 = 6 x 10^1 = 60

This is the same for the other number systems. The only difference is the powers or the weights.

- The powers of the base are used for the weights.

For binary the weights are in powers of 2

For octal weights are in powers of 8

For hexadecimal the weights are in powers of 16.

Conversions

It is possible to convert a number from one number system to another.

We are familiar with the decimal number system.

For ease of conversions, it is prudent to convert the number to decimal number system

2. **Convert 156_8 to hexadecimal number system.**

Sol

Step1: Convert 156_8 to decimal first

$156_8 = 1x8^2 + 5x8^1 + 6x8^0$

$= 64 + 40 + 6$

$= 110_{10}$

Step2: Convert 110_{10} to Hexadecimal

Divide the number by 16 repeatedly until you get 0 each time noting down the remainder

		REM	
2	110	0	
2	55	1	
2	27	1	
2	13	1	Read the remainder upwards.
2	6	0	
2	3	1	
2	1	1	
	0		

The answer is **1101110_2.** Therefore **$156_8 = 1101110_2$.**

Real Numbers

These are number with fractions. These numbers are divided into two portions; the whole number part and the fraction part.

Converting the whole number part to the required number system is done as above.

For the fraction part, convert it to decimal first, and then multiply the decimal result with the required number base repeatedly until you get 0 each time noting the whole number carry.

Numbers with fractions are also called floating point numbers. Numbers with no fractions are called fixed point numbers.

Example

Convert $AD2.C10_{16}$ to Binary Number System

Solution

Step 1

Divide the number into two portions

$AD2_{16}$ and $0.C10_{16}$

Step 2

Treat whole number as usual

That is: convert to decimal and divide the decimal number with 2 repeatedly until 0 is obtained noting down the Rems after each division.

$AD2_{16} = Ax16^2 + Dx16^1 + 2X16^0 = 2560 + 208 + 2 = 2770_{10}$

Convert 2770_{10} to Binary = $1010\ 1101\ 0010_2$

Step 3

Convert the fraction part into decimal.

$0.C10_{16}= Cx16^{-1} + 1x16^{-2} + 0x16^{-3}$

= 12x1/16 + 1x 1/16x1/16 + 0

= 12/16 + 1/256 +0

= 0.75 + 0.00390625

= $\mathbf{0.75390625_{10}}$

Converting this to Binary, multiply by 2 and note the carries until 0 is obtained.

	CARRY	
0.75390625		
X 2		
0.5078125	1	
X 2		
0.015625	1	
X 2		
0.03125	0	
X 2		
0.0625	0	Read the carry downwards.
X 2		
0.125	0	
X 2		
0.25	0	Therefore $0.C10_{16} = 0.1100\ 0001_2$
X 2		
0.5	0	
X 2		
0.0	1	

Therefore $AD2.C10_{16}$ = $\mathbf{1010\ 1101\ 0010.\ 1100\ 0001_2}$

Any other conversion is treated the same.

Arithmetic Operations

These are the addition, subtraction, division and multiplication of numbers in number system. For arithmetic operations the numbers being operated on must be in the same number system.

Operations are similar to those done in decimal number system.

Examples

Evaluate

i. **$138_{Ten} + 406_{Ten}$**
ii. **$1110_{Two} + 1001_{Two}$**
iii. **$AC12_{Hex} + 134F_{Hex}$**

Solution

(i) $138_{Ten} + 406_{Ten}$

$$
\begin{array}{r}
138 \\
+\ 406 \\
\hline
544
\end{array}
$$

The answer is **544_{Ten}**

(ii) $1110_{Two} + 1001_{Two}$

$$
\begin{array}{r}
1110 \\
+\ 1001 \\
\hline
10111
\end{array}
$$

The answer is **10111_{Two}**

(iii) $AC12_{Hex} + 134F_{Hex}$

$$
\begin{array}{r}
AC12 \\
+\ 134F \\
\hline
BF61
\end{array}
$$

The answer is **$BF61_{Hex}$**.

NOTE:

Subtraction, multiplication and division are done in the same way.

Complement in a number system

Complements are used in the digital computers in order to simplify the subtraction operation and for the logical manipulations. For each radix-r system (radix r represents base of number system) there are two types of complements.

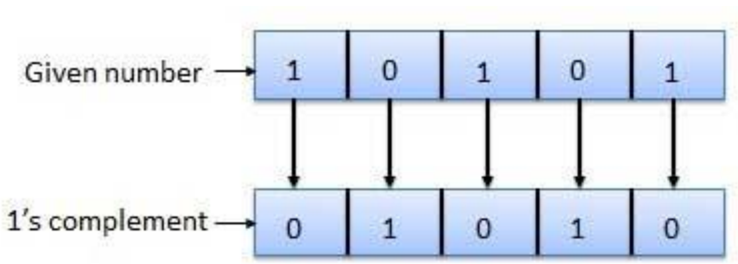
S.N.	Complement	Description
1	Radix Complement	The radix complement is referred to as the r's complement
2	Diminished Radix Complement	The diminished radix complement is referred to as the (r-1)'s complement

Binary system complements

As the binary system has base r = 2. So the two types of complements for the binary system are 2's complement and 1's complement.

a. **1's complement**

The 1's complement of a number is found by changing all 1's to 0's and all 0's to 1's. This is called as taking complement or 1's complement. Example of 1's Complement is as follows.

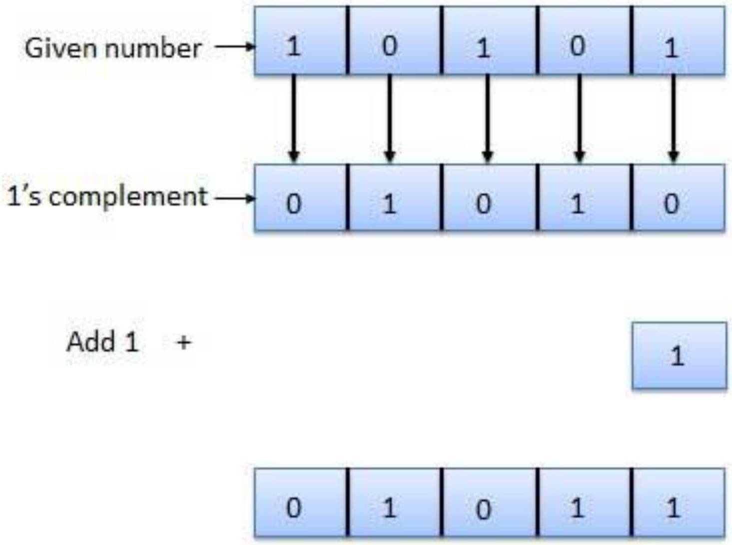


b. **2's complement**

The 2's complement of binary number is obtained by adding 1 to the Least Significant Bit (LSB) of 1's complement of the number.

2's complement = 1's complement + 1

Example of 2's Complement is as follows.



Binary arithmetic is essential part of all the digital computers and many other digital system.

Binary Addition

It is a key for binary subtraction, multiplication, division. There are four rules of binary addition.

Case	A + B	Sum	Carry
1	0 + 0	0	0
2	0 + 1	1	0
3	1 + 0	1	0
4	1 + 1	0	1

In fourth case, a binary addition is creating a sum of (1 + 1 = 10) i.e. 0 is written in the given column and a carry of 1 over to the next column.

Example − Addition

0011010 + 001100 = 00100110

```
   1 1          carry
  0 0 1 1 0 1 0   = 26₁₀
 +0 0 0 1 1 0 0   = 12₁₀
 ---------------
  0 1 0 0 1 1 0   = 38₁₀
```

Binary Subtraction

Subtraction and Borrow, these two words will be used very frequently for the binary subtraction. There are four rules of binary subtraction.

Case	A	-	B	Subtract	Borrow
1	0	-	0	0	0
2	1	-	0	1	0
3	1	-	1	0	0
4	0	-	1	0	1

Example − Subtraction

0011010 - 001100 = 00001110

$$
\begin{array}{rl}
1\ 1 & \text{borrow} \\
0\ 0\ \cancel{1}\ \cancel{1}\ 0\ 1\ 0 & = 26_{10} \\
-\ 0\ 0\ 0\ 1\ 1\ 0\ 0 & = 12_{10} \\
\hline
0\ 0\ 0\ 1\ 1\ 1\ 0 & = 14_{10}
\end{array}
$$

Binary Multiplication

Binary multiplication is similar to decimal multiplication. It is simpler than decimal multiplication because only 0s and 1s are involved. There are four rules of binary multiplication.

Case	A	x	B	Multiplication
1	0	x	0	0
2	0	x	1	0
3	1	x	0	0
4	1	x	1	1

Example − Multiplication

Example:

0011010 x 001100 = 100111000

```
      0 0 1 1 0 1 0    = 26₁₀
    x 0 0 0 1 1 0 0    = 12₁₀
  -----------------
      0 0 0 0 0 0 0
    0 0 0 0 0 0 0
  0 0 1 1 0 1 0
0 0 1 1 0 1 0
-------------------
0 1 0 0 1 1 1 0 0 0    = 312₁₀
```

Binary Division

Binary division is similar to decimal division. It is called as the long division procedure.

Example − Division

101010 / 000110 = 000111

```
           1 1 1        = 7₁₀
        ____________
000110 ) 1 0 1 0 1 0    = 42₁₀
        -1 1 0          = 6₁₀
        ------
         1 0 0 1
        -1 1 0
        --------
           1 1 0
          -1 1 0
          ------
               0
```

CODES

A computer accepts data in digital format. Most systems in the environment handle data in analogue format. For example, a keyboard keys are labeled using alphabetic, numeric and special characters. Data keyed into a computer via a keyboard has to be converted to digital format. Various schemes, developed by different organizations are used. Three main schemes used are:-

- The American Standard Code for Information Interchange – ASCII: developed by US Military
- The Extended Binary Coded Decimal Interchange Code – EBCDIC: Developed by the IBM
- The International Alphabet version 5 – IA5: developed by the ISO.

Before appreciating these schemes lets look at the following basic codes:-

Binary Codes

Binary coded Octal (BCO)

Binary coded Decimal (BCD)

Binary coded Hexadecimal (BCH)

Decimal Number	Binary Code	Binary Coded Octal	Binary Coded Decimal	Binary Coded Hexadecimal
0	0	000	0000	0000
1	1	001	0001	0001
2	10	010	0010	0010
3	11	011	0011	0011
4	100	100	0100	0100
5	101	101	0101	0101
6	110	110	0110	0110
7	111	111	0111	0111
8	1000	001000	1000	1000
9	1001	001001	1001	1001
10	1010	001010	00010000	1010

11	1011	001011	00010001	1011
12	1100	001100	00010010	1100
13	1101	001101	00010011	1101
14	1110	001110	00010100	1110
15	1111	001111	00010101	1111
16	10000	010000	00010110	00010000

Note:

- To represent octal equivalent of the decimal numbers in the binary form, three bits are used.
- To represent the hexadecimal equivalent of the decimal number in the binary form, four bits are used.

ASCII Code

This is a 7-bit code. With this code 2^7 or 128 characters are defined.

See the ASCII Character table below.

Dec	Hx	Oct	Char		Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr
0	0	000	NUL	(null)	32	20	040		Space	64	40	100	@	@	96	60	140	`	`
1	1	001	SOH	(start of heading)	33	21	041	!	!	65	41	101	A	A	97	61	141	a	a
2	2	002	STX	(start of text)	34	22	042	"	"	66	42	102	B	B	98	62	142	b	b
3	3	003	ETX	(end of text)	35	23	043	#	#	67	43	103	C	C	99	63	143	c	c
4	4	004	EOT	(end of transmission)	36	24	044	$	$	68	44	104	D	D	100	64	144	d	d
5	5	005	ENQ	(enquiry)	37	25	045	%	%	69	45	105	E	E	101	65	145	e	e
6	6	006	ACK	(acknowledge)	38	26	046	&	&	70	46	106	F	F	102	66	146	f	f
7	7	007	BEL	(bell)	39	27	047	'	'	71	47	107	G	G	103	67	147	g	g
8	8	010	BS	(backspace)	40	28	050	(	(	72	48	110	H	H	104	68	150	h	h
9	9	011	TAB	(horizontal tab)	41	29	051	)	)	73	49	111	I	I	105	69	151	i	i
10	A	012	LF	(NL line feed, new line)	42	2A	052	*	*	74	4A	112	J	J	106	6A	152	j	j
11	B	013	VT	(vertical tab)	43	2B	053	+	+	75	4B	113	K	K	107	6B	153	k	k
12	C	014	FF	(NP form feed, new page)	44	2C	054	,	,	76	4C	114	L	L	108	6C	154	l	l
13	D	015	CR	(carriage return)	45	2D	055	-	-	77	4D	115	M	M	109	6D	155	m	m
14	E	016	SO	(shift out)	46	2E	056	.	.	78	4E	116	N	N	110	6E	156	n	n
15	F	017	SI	(shift in)	47	2F	057	/	/	79	4F	117	O	O	111	6F	157	o	o
16	10	020	DLE	(data link escape)	48	30	060	0	0	80	50	120	P	P	112	70	160	p	p
17	11	021	DC1	(device control 1)	49	31	061	1	1	81	51	121	Q	Q	113	71	161	q	q
18	12	022	DC2	(device control 2)	50	32	062	2	2	82	52	122	R	R	114	72	162	r	r
19	13	023	DC3	(device control 3)	51	33	063	3	3	83	53	123	S	S	115	73	163	s	s
20	14	024	DC4	(device control 4)	52	34	064	4	4	84	54	124	T	T	116	74	164	t	t
21	15	025	NAK	(negative acknowledge)	53	35	065	5	5	85	55	125	U	U	117	75	165	u	u
22	16	026	SYN	(synchronous idle)	54	36	066	6	6	86	56	126	V	V	118	76	166	v	v
23	17	027	ETB	(end of trans. block)	55	37	067	7	7	87	57	127	W	W	119	77	167	w	w
24	18	030	CAN	(cancel)	56	38	070	8	8	88	58	130	X	X	120	78	170	x	x
25	19	031	EM	(end of medium)	57	39	071	9	9	89	59	131	Y	Y	121	79	171	y	y
26	1A	032	SUB	(substitute)	58	3A	072	:	:	90	5A	132	Z	Z	122	7A	172	z	z
27	1B	033	ESC	(escape)	59	3B	073	;	;	91	5B	133	[	[	123	7B	173	{	{
28	1C	034	FS	(file separator)	60	3C	074	<	<	92	5C	134	\	\	124	7C	174			|
29	1D	035	GS	(group separator)	61	3D	075	=	=	93	5D	135	]	]	125	7D	175	}	}
30	1E	036	RS	(record separator)	62	3E	076	>	>	94	5E	136	^	^	126	7E	176	~	~
31	1F	037	US	(unit separator)	63	3F	077	?	?	95	5F	137	_	_	127	7F	177	&#127;	DEL

Source: www.LookupTables.com

Computers manipulate data as a group of 8-bits or a byte. Thus the ASCII code has to be padded to form 8bits. Padding is the process of adding an extra bit to an existing bit stream. The extra bit is used for other purposes depending on application.

In data communication, the extra bit added to the 7bit ASCII code is called a parity bit. It is used for checking errors in the transmitted codes.

In Printers, a zero is commonly added to the ASCII code to form a stream of 8-bits for the printers to recognize the byte. A zero is added on the MSB end.

EBCDIC code

This is an 8-bit code developed by IBM. The bye is divided into two parts of 4 bits each. The first nibble is called the zone and the other nibble represents the character. With 8bits 256 characters are represented. These form 16 zones: 0–F, with 16 characters in each zone.

Numerals 0-9 are in zone 3; 30 -39

A-Z start in zone 4; 41 -5A

a-z star in zone 6; 61 -7A

IA5 codes

This is an ITU-T standard. It is a 7-bit character code encoded as 8-bits. It is similar to ASCII except for some few characters.

Chapter Two

Basic computer organization & design based on Von Neumann architecture

Introduction

A micro computer system basically consists of: -

- Hardware
- Software

A. Hardware

These are the tangible components of a computer and include: -
The screen, keyboard, mouse, speakers, floppy drive, CD drive, Hard drive RAM, ROM, hard disks, Flash disks, CPU, printer, interconnecting cables, etc.

The computer hardware performs three basic operations. These are: -

- Input of data
- Processing and storage of data
- To Output data

Different kinds of computers use different kinds of hardware to input, process and store, and output information.

a. Input hardware

These are the hardware used to enter data and instructions into the computer. They are referred to as **Input Devices**. There are two types of input devices - direct and indirect input device

i. Direct Input devices

These are machine data inputs. These include scanners, barcode readers, sensors, voice recognition devices, speakers, digital camera etc.

ii. Indirect Input devices

These are human entry devices such as keyboard, joystick, light pens, mouse, etc

b. Processing and storage hardware

These include the CPU, main storage, ROM, RAM, hard disks, secondary storage, clock, etc

c. Output hardware

They are also referred to as **output devices**. They receive information and data form the CPU. They allow data from the computer to be converted in a human readable form.

There are two types of output devices - **hard copy and soft copy**.
Examples of hard copy output devices are printers, plotters, microfilm, video, etc
Examples of soft copy output devices are Monitor or the Visual display Unit, Voice, sound cards, another computer, etc.

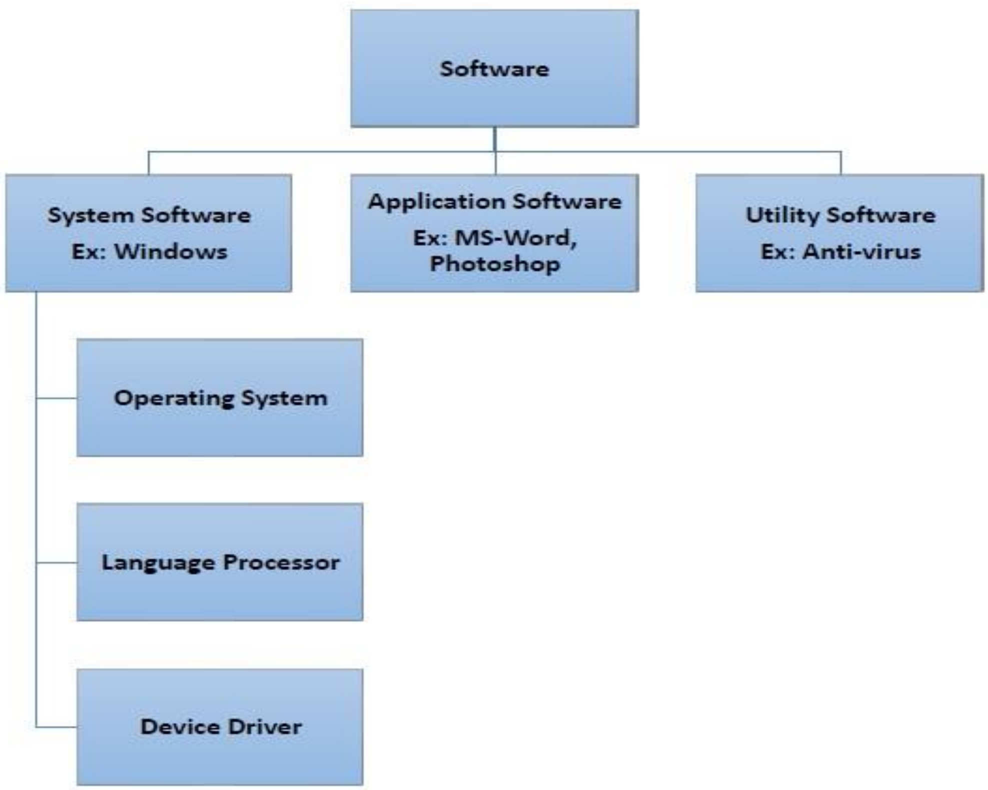
B. Software

Computer software is the set of instructions written in a specific computer language to direct the computer in the process of solving or performing a specific task. The instructions are executed in a precise order. The instructions can be executed as many times, each time yielding a potentially different result depending on the options and data provided by the user. To perform a task, the instructions needed must all be executed to completion.
Different kinds of software are designed to perform different tasks.

Types of computer software
Basically, there are three types of computer software: -

- System Software
- Application Software
- Utility Software

Let us discuss them in detail.



a. System Software

Software required to run the hardware parts of the computer and other application software are called **system software**. System software acts as **interface** between hardware and user applications. An interface is needed because hardware devices or machines and humans speak in different languages.

Machines understand only binary language i.e. 0 (absence of electric signal) and 1 (presence of electric signal) while humans speak in English, French, German, Tamil, Hindi and many other languages. English is the pre-dominant language of interacting with computers. Software is required to convert all human instructions into machine understandable instructions. And this is exactly what system software does.

Based on its function, system software is of three types −

- Operating System
- Language Processor
- Device Drivers

i. Operating System

System software that is responsible for functioning of all hardware parts and their interoperability to carry out tasks successfully is called **operating system (OS)**. OS is the first software to be loaded into computer memory when the computer is switched on and this is called **booting**. OS manages a computer's basic functions like storing data in memory, retrieving files from storage devices, scheduling tasks based on priority, etc.

ii. Language Processor

As discussed earlier, an important function of system software is to convert all user instructions into machine understandable language. When we talk of human machine interactions, languages are of three types –

- **Machine-level language** − this language is nothing but a string of 0s and 1s that the machines can understand. It is completely machine dependent.
- **Assembly-level language** − this language introduces a layer of abstraction by defining **mnemonics**. **Mnemonics** are English like words or symbols used to denote a long string of 0s and 1s. For example, the word "READ" can be defined to mean that computer has to retrieve data from the memory. The complete **instruction** will also tell the memory address. Assembly level language is **machine dependent**.
- **High level language** − this language uses English like statements and is completely independent of machines. Programs written using high level languages are easy to create, read and understand.

Program written in high level programming languages like Java, C++, etc. is called **source code**. Set of instructions in machine readable form is called **object code** or **machine code**. **System software** that converts source code to object code is called **language processor**. There are three types of language interpreters−

- **Assembler** − Converts assembly level program into machine level program.
- **Interpreter** − Converts high level programs into machine level program line by line.
- **Compiler** − Converts high level programs into machine level programs at one go rather than line by line.

- **Debugger**- Checks for bugs or errors in a program

iii. Device Drivers

System software that controls and monitors functioning of a specific device on computer is called **device driver**. Each device like printer, scanner, microphone, speaker, etc. that needs to be attached externally to the system has a specific driver associated with it. When you attach a new device, you need to install its driver so that the OS knows how it needs to be managed.

b. Application Software

A software that performs a single task and nothing else is called **application software**. Application software are very specialized in their function and approach to solving a problem. So, a spreadsheet software can only do operations with numbers and nothing else. A hospital management software will manage hospital activities and nothing else. Here are some commonly used applications software −

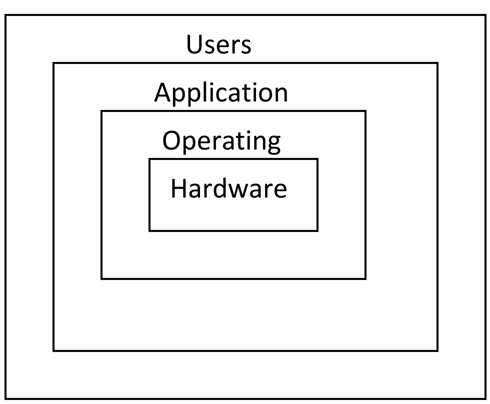
- Word processing
- Spreadsheet
- Presentation
- Database management
- Multimedia tools

c. Utility Software

Application software that assists system software in doing their work is called **utility software**. Thus, utility software is actually a cross between system software and application software. Examples of utility software include −

- Antivirus software
- Disk management tools
- File management tools
- Compression tools
- Backup tools

Relationship diagram for a microcomputer system



The hardware is in the core of the computer system. It interacts with the operating system only.

The operating system can interact with the hardware and the application system, but the application system cannot interact with the hardware because the two layers are not adjacent.

The application system can interact with the users and the operating system. Operating system cannot interact with the users.

The user layer can only interact with the application system layer, but cannot interact with the operating system and hardware layers.

Categories of software

Computer software can be categorized as Proprietary or open source.

a. **Proprietary software**

   It is software that has restrictions on using and copying. It is developed with the aim of making profits. One has to have a license to use the software. Modification, distribution and resale of this software is also restricted.

b. **Open-source software**

It is also called free ware. This is software that is available under copy right licenses that permit the users to study, change and improve the software, and to redistribute it in the modified or unmodified form. This makes the product more understandable, reliable and more accessible while it is in the marketplace.

Von Neunmann Architecture

* Refer von neumann architecture pdf *

1. **Arithmetic Logic Unit**

It performs all arithmetic operations and logic comparisons.

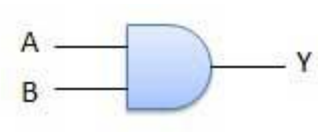
Arithmetic operations include:- +, -, x, /

Logic operations include:- = , > =, <=,AND,OR, NOT

This can be represented using a **Truth table**. A truth table is a representation of inputs and outputs of a function ie it relates the inputs and outputs of a function.

a. **AND Operator**

Logic diagram

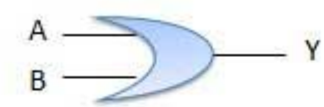


Truth Table

Inputs		Output
A	B	AB
0	0	0
0	1	0
1	0	0
1	1	1

b. OR Operator

Logic diagram



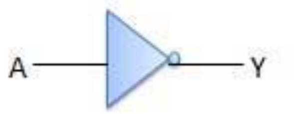
Truth Table

Inputs		Output
A	B	A + B
0	0	0
0	1	1
1	0	1
1	1	1

c. NOT Operator

NOT gate is also known as **Inverter**. It has one input A and one output Y.

Logic diagram



Truth Table

Inputs	Output
A	B
0	1
1	0

2. **Registers**

Registers are essentially extremely fast memory locations within the CPU that are used to create and store the results of CPU operations and other calculations.

The register set differs from one computer architecture to another. It is usually a combination of general-purpose and special-purpose registers.

a. **Stack Pointer (SP)**

This points to the memory location where the CPU lastly saved some data. If the CPU requires to save another data, it will save in the address next to the one pointed by the SP. If this happens the contents of the SP are automatically incremented.

b. **Processor Status Register or Processor Status Word (PSW) Register**

The microprocessor executes many tasks at the same time. When the microprocessor receives a higher priority request, it suspends the task it is executing, saves its status in the PSW register and starts executing the higher priority task.

A task that is being executed is called a process.

The PSW register is used to store the status of all the processes that are being executed by the microprocessor or the CPU.

c. **Instruction Register**

It is used to hold the instruction that is currently being executed.

d. **Program counter (PC)**

When the CPU is executing a task, it essentially executes a series of commands. The next instruction or command to be executed is stored in the program counter register. Thus whenever a CPU finishes executing a command or an instruction, it fetches the next instruction from the PC.

e. Accumulator (A)

This is another special register. It is used during Arithmetic and logic operations. It is the register in which operations are done. It also holds the results of the operation.

f. Memory Data Register

It contains the data to be stored in the computer storage (e.g. RAM), or the data after a fetch from the computer storage. It acts like a buffer and holds anything that is copied from the memory ready for the processor to use it. MDR hold the information before it goes to the decoder.

g. Memory Address Register

This register holds the memory addresses of data and instructions. This register is used to access data and instructions from memory during the execution phase of an instruction. Suppose CPU wants to store some data in the memory or to read the data from the memory. It places the address of the-required memory location in the MAR**.**

3. Control Unit

It provides all the control signals to the ALU and to the set of special registers used by the CPU. It also decodes the instructions, retrieves data from and sends data to memory.

It is the main component that directs the system operations by sending control signals to the data path. These signals control the flow of data within the CPU and between the CPU and external units such as memory and I/O. Control buses generally carry signals between the control unit and other computer components in a clock-driven manner. The system clock produces a continuous sequence of pulses in a specified duration and frequency.

There are mainly two different types of control units:

- **Microprogrammed**
- **Hardwired**

i. Microprogrammed control

The control signals associated with operations are stored in special memory units inaccessible by the programmer as control words. A control word is a microinstruction that specifies one or more micro-operations.

A sequence of microinstructions is called a microprogram, which is stored in a ROM or RAM called a control memory (CM).

A microprogram consists of a sequence of microinstructions. A microinstruction is a vector of bits, where each bit is a control signal, condition code, or the address of the next microinstruction. Microinstructions are fetched from CM the same way program instructions are fetched from main memory

Microinstructions can be classified as:-

- Horizontal
- Vertical.

Individual bits in horizontal microinstructions correspond to individual control lines. Horizontal microinstructions are long and allow maximum parallelism since each bit controls a single control line.

In vertical microinstructions, control lines are coded into specific fields within a microinstruction. Decoders are needed to map a field of *k* bits to 2^k possible combinations of control lines.

For example, a 3-bit field in a microinstruction could be used to specify any one of eight possible lines. Because of the encoding, vertical microinstructions are much shorter than horizontal ones. Control lines encoded in the same field cannot be activated simultaneously. Therefore, vertical microinstructions allow only limited parallelism. It should be noted that no decoding is needed in horizontal microinstructions while decoding is necessary in the vertical case

ii. Hardwired control

Fixed logic circuits that correspond directly to the Boolean expressions are used to generate the control signals.

Clearly hardwired control is faster than microprogrammed control. However, hardwired control could be very expensive and complicated for complex systems. Hardwired control is more economical for small control units. It should also be noted that microprogrammed control could adapt easily to changes in the system design. We can easily add new instructions without changing hardware. Hardwired control will require a redesign of the entire systems in the case of any change.

Review Questions

1. **Using a well labelled diagram, explain the main components of a processor**
2. **. What are the main differences between the following pairs?**
   a. **Vertical and horizontal microinstructions**
   b. **Microprogramming and hardwired control**