

Higher Secondary Course

Computer Science



Class - XI

Part - I



Government of Kerala
DEPARTMENT OF EDUCATION

State Council of Educational Research and Training (SCERT); Kerala
2016

THE NATIONAL ANTHEM

Jana-gana-mana adhinayaka, jaya he
Bharatha-bhagya-vidhata.
Punjab-Sindh-Gujarat-Maratha
Dravida-Utkala-Banga
Vindhya-Himachala-Yamuna-Ganga
Uchchala-Jaladhi-taranga
Tava subha name jage,
Tava subha asisa mage,
Gahe tava jaya gatha.
Jana-gana-mangala-dayaka jaya he
Bharatha-bhagya-vidhata.
Jaya he, jaya he, jaya he,
Jaya jaya jaya, jaya he!

PLEDGE

India is my country. All Indians are my brothers and sisters.

I love my country, and I am proud of its rich and varied heritage. I shall always strive to be worthy of it.

I shall give respect to my parents, teachers and all elders and treat everyone with courtesy.

I pledge my devotion to my country and my people. In their well-being and prosperity alone lies my happiness.

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Dear students,

Computer Science, a subject belonging to the discipline of Science and of utmost contemporary relevance, needs continuous updating. The Higher Secondary Computer Science syllabus has been revised with a view to bringing out its real spirit and dimension. The constant and remarkable developments in the field of computing as well as the endless opportunities of research in the field of Computer Science and Technology have been included.

This textbook is prepared strictly in accordance with the revised syllabus for the academic year 2014 - 15. It begins with the historical developments in computing and familiarises the learner with the latest technological advancements in the field of computer hardware, software and network. The advancement in computer network, Internet technology, wireless and mobile communication are also dealt with extensively in the content. In addition to familiarising various services over the Internet, the need to be concerned about the factors that harness morality and the awareness to refrain from cyber security threats are also highlighted.

The major part of the textbook as well as the syllabus establishes a strong foundation to construct and enhance the problem solving and programming skills of the learner. The multi-paradigm programming language C++ is presented to develop programs which enable computers to manage different real life applications effectively. The concepts and constructs of the principles of programming are introduced in such a way that the learner can grasp the logic and implementation methods easily.

I hope this book will meet all the requirements for stepping to levels of higher education in Computer Science and pave your way to the peak of success.

Wish you all success.

Dr P. A. Fathima

Director, SCERT; Kerala

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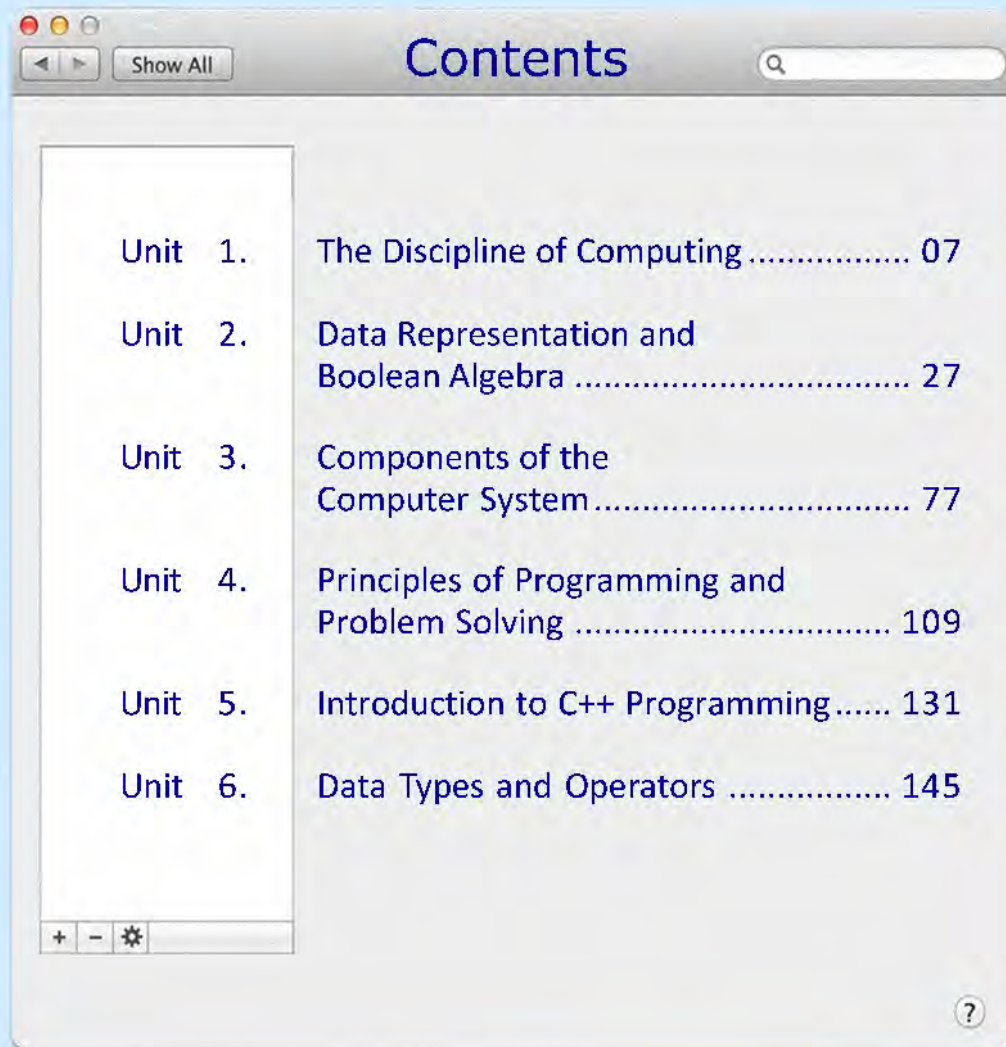
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Icons used in this textbook



Let us do



Check yourself



Information box



Lab activities



Learning outcomes

Key concepts

- **Computing milestones and machine evolution**
 - Counting and the evolution of the positional number system
 - Evolution of the computing machine
- **Generations of computers**
 - First generation computers
 - Second generation computers
 - Third generation computers
 - Fourth generation computers
 - Fifth generation computers
- **Evolution of computing**
 - Programming languages
 - Algorithm and computer programs
 - Theory of computing

The Discipline of Computing

Computers now play a major role in almost every aspect of life and influence our lives in one way or the other. Today, almost everyone is a computer user and many are computer programmers. Getting computers to do what you want them to do requires intensive hands-on experience. But computer science can be seen on a higher level, as a science of problem-solving. Computer scientists must be able to analyse problems and design solutions for real world problems. The Computer Science discipline covers a wide range of topics from theoretical aspects like design of algorithms to more practical aspects like application development and its implementation. The discipline of Computer Science involves the systematic study of algorithmic processes – their theory, analysis, design, efficiency, implementation and application – that describe and transform information.

The concept of computing has evolved from the abacus to super computers of today. This chapter discusses the evolution of computing devices and provides an overview of the different generations of computers. The evolution of programming languages and the contributions of Alan Turing to computer science are also discussed.

1.1 Computing milestones and machine evolution

In ancient times people used stones for counting. They made scratches on walls or tied knots in ropes to record information. Progressively many attempts had been made to replace these manual computing techniques with faster computing machines. In this section, we will have a look at the ancient methods of counting and the evolution of the positional number system.

1.1.1 Counting and the evolution of the positional number system

The idea of number and the process of counting goes back far before history began to be recorded. It is believed that even the earliest humans had some sense of 'more' or 'less'. As human beings differentiated into tribes and groups, it became necessary to be able to know the number of members in the group and in the enemy's camp. And it was important for them to know if the flock of sheep or other animals was increasing or decreasing in size. In order to count items, such as animals, 'sticks' were used, each stick representing one animal or object.

Let us now see how the number system evolved. It is important to note that the system that we use everyday is a product of thousands of years of progress and development. It represents contributions of many civilisations and cultures. The number system is a method in which we represent numbers. The chronological development of the number system throughout the history is discussed below.

To begin with let us see the Egyptian number system that emerged around 3000BC. It used 10 as a radix (base). They had unique symbols for 1 to 9, 10 to 90, 100 to 900 and 1000 to 9000. As the Egyptians write from right to left, the largest power of ten appears to the right of the other numerals.

Later on, the era of Sumerian/Babylonian number system began. It used 60 as its number base, known as the sexagesimal system. Numerals were written from left to right. It was the largest base that people ever used in number systems. They did not use any symbol for zero, but they used the idea of zero. When they wanted to express zero, they just left a blank space within the number they were writing.

The Chinese number system emerged around in 2500 BC. It was the simplest and the most efficient number system. The Chinese had numbers from 1 to 9. It had the base 10, very similar to the one we use today. They used small bamboo rods to represent the numbers 1 to 9.

Approximately in 500 BC, the Greek number system known as Ionian number system evolved. It was a decimal number system and the Greeks also did not have any symbol for zero.

The Romans started using mathematics for more practical purposes, such as in the construction of roads, bridges, etc. They used 7 letters (I, V, X, L, C, D and M) of the alphabet for representing numbers.

The Mayans used a number system with base 20. There is a simple logic behind this base 20. It is the sum of the number of fingers and toes. This number system could produce very accurate astronomical observations and make measurements with greater accuracy.

The Hindu-Arabic numeral system actually originated in India, around 1500 years ago. It was a positional decimal numeral system and had a symbol for zero. This invention can indeed be termed as one of India's greatest contributions to the world. Later on many of the countries adopted this numeral system. Now let us discuss the evolution of computing machines.

1.1.2 Evolution of the computing machine

During the period from 3000 BC to 1450 AD, human beings started communicating and sharing information with the aid of simple drawings and later through writings. The introduction of numbers led to the invention of Abacus, the first computing machine. In the following section, we will examine some important milestones in the evolution of computing machines.

a. Abacus

Abacus was discovered by the Mesopotamians around 3000 BC. The word 'abacus' means calculating board. An abacus consisted of beads on movable rods divided into two parts. The abacus may be considered the first computer for basic arithmetical calculations. An abacus is shown in Figure 1.1.

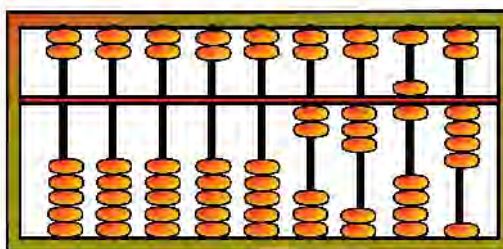
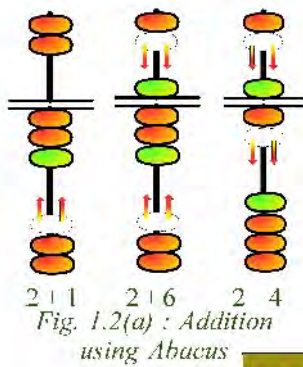


Fig. 1.1 : Abacus

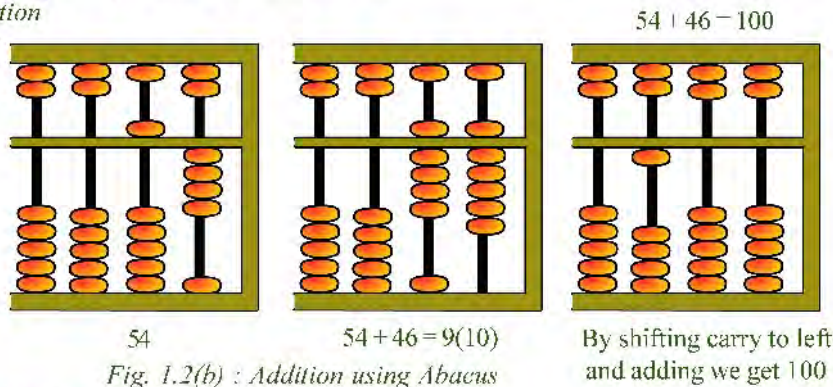
The abacus is also called a counting frame, a calculating tool for performing arithmetic operations. The Chinese improved abacus as a frame holding vertical wires, with seven beads on each wire. A horizontal divider separates the top two beads from the bottom five. Addition and multiplication of numbers was done using the place value of digits and position of beads in an abacus.

The abacus works on the basis of the place value system. Reading it is almost like reading a written numeral. Each of the five beads below the bar has a value of 1. Each of the two beads above the bar has a value of 5. The beads which are pushed



against the bar represent the number. The number on the abacus given in Figure 1.1 is 2364.

Abacus is used even today by children to learn counting. A skilled abacus operation can be as fast as a hand held calculator. Figures 1.2(a) shows the addition of two single digit numbers. Figure 1.2(b) shows how two numbers (54 and 46) are added.



b. Napier's bones

John Napier was a mathematician who devised a set of numbering rods known as Napier's bones in 1617 AD, by which a multiplication problem could be easily performed. These numbered rods could perform multiplication of any number by a number in the range of 2-9. There are 10 bones corresponding to the digits 0-9 and a special eleventh bone that is used to represent the multiplier. This device was known as Napier's bones. John Napier also invented logarithm in 1614, that reduced tedious multi-digit multiplications to addition problems. A representation of Napier's bones is given in Figure 1.3.



	1	2	3	4	5	6	7	8	9
1	1	2	3	4	5	6	7	8	9
2	2	4	6	8	10	12	14	16	18
3	3	6	9	12	15	18	21	24	27
4	4	8	12	16	20	24	28	32	36
5	5	10	15	20	25	30	35	40	45
6	6	12	18	24	30	36	42	48	54
7	7	14	21	28	35	42	49	56	63
8	8	16	24	32	40	48	56	64	72
9	9	18	27	36	45	54	63	72	81

Fig. 1.3 : John Napier (1550 - 1617) and Napier's Bones

The strips of Napier's bones are the times tables. Each square gives $2 \times$ number, $3 \times$ number and so on, but the tens and units are written above and below a slanting line respectively. Napier's bones is good for multiplying a long number by a single digit number. Let us multiply 425928 by 7. First take the strips for 4, 2, 5, 9, 2 and 8, and fit them into the frame. Look at the squares next to the 7 on the side. It is coloured green in Figure 1.4. Now read the digits – any number within slanting lines must be added. So the answer is $2(8+1)(4+3)(5+6)(3+1)(4+5)6$ or 297(11)496. All the digits except 11 are in their position. 11 needs to have 10 carried to the left. This makes $29(7+1)1496$ or 2981496, which is the correct answer.

1	4	2	5	9	2	8	1	4	2	5	9	2	8
2	8	4	1	1	8	4	1	8	4	1	8	4	1
3	1	2	6	1	5	2	7	6	2	4	3	2	6
4	1	6	8	2	0	3	6	8	3	2	4	1	8
5	2	0	1	2	5	4	5	0	4	0	5	1	0
6	2	4	1	2	3	5	4	1	2	4	8	3	6
7	2	8	1	4	3	6	1	4	5	6	3	2	4
8	3	2	1	6	4	7	2	1	6	4	8	3	2
9	3	6	1	8	4	8	1	8	7	2	6	4	1

$7 \times 425928 =$

$- 2(8+1)(4+3)(5+6)(3+1)(4+5)6$
 $- 297(11)496 = 2981496$

Fig. 1.4 : Multiplication using Napier's Bones

c. Pascaline

Blaise Pascal was a French mathematician and one of the first modern scientists to develop a calculator. In 1642, at the age of 19, he developed a computing machine that was capable of adding and subtracting two numbers directly and that could multiply and divide by repetition. Pascal invented this arithmetic calculator to assist his father in his work as a tax collection supervisor. This machine was operated by dialing a series of wheels, gears and cylinders. He called it 'Pascaline'. Figure 1.5 shows a Pascaline.



Fig. 1.5 : Blaise Pascal (1623 - 1662) and Pascaline

Consider adding the numbers 20 and 81 using Pascaline. Initially, the Pascaline will be set to 0 for all the six digits. To dial 20, you just have to put your finger into the space between the spokes next to digit 2 of the second wheel and rotate the wheel in clockwise direction until your finger strikes against the fixed stop on the bottom of the wheel. This rotation transmits the value of two into the second window from the right. Now the machines will display number 0020.



Pascaline wheel

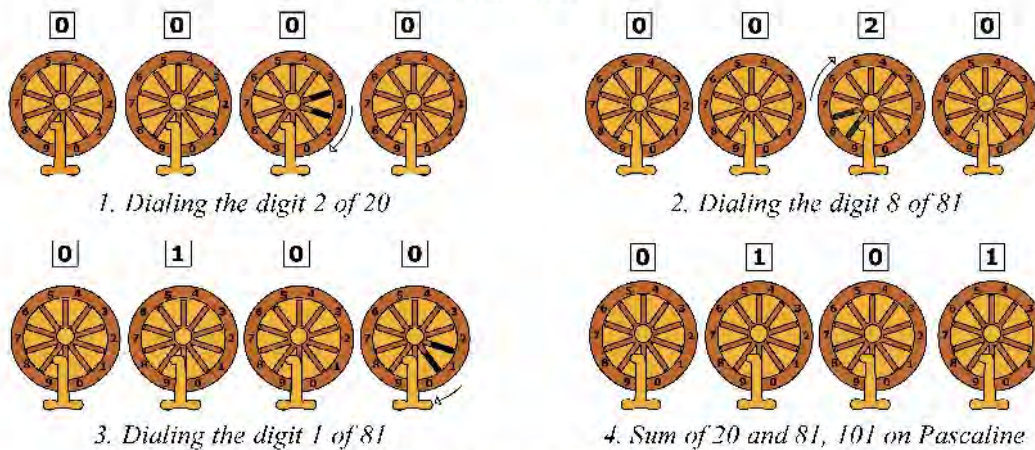


Fig. 1.6 : Adding using Pascaline

To dial 81, put your finger into the space between the spokes next to digit 8 of the second wheel and rotate it. After the second drum reaches number 9, the gears inside Pascaline will carry to the next drum one unit and the third drum of the machine will rotate by one tenth. So after the end of dialing number 8, the machine will display the number 100. Now put your finger into the space between the spokes next to digit 1 and rotate it in the same way you did before. Now the machine will display the number 0101, which is the final result of addition.

d. Leibniz's calculator

In 1673 the German mathematician-philosopher Gottfried Wilhelm von Leibniz designed a calculating machine called the Step Reckoner. The Step Reckoner expanded on Pascal's ideas and extended the capabilities to perform multiplication and division as well. Leibniz successfully introduced this calculator onto the market. His unique, drum-shaped gears formed the basis of many successful calculator designs in later years.



Fig. 1.7 : Gottfried Wilhelm von Leibniz (1646 - 1716) and Leibniz Calculator

e. Jacquard's loom

The Jacquard loom is a mechanical loom, invented by Joseph Marie Jacquard in 1801, that simplifies the process of manufacturing textiles with complex patterns. The loom is controlled by punched cards with punched holes, each row of which corresponds to one row of the design. Multiple rows of holes are punched on each card and the many cards that compose the design of the textile are joined together in order. The Jacquard loom not only reduced the amount of human labour, but also allowed to store patterns on cards to be utilised again to create the same product. These punched cards were innovative because the cards had the capability to store information on them. This ability to store information triggered the computer revolution. The punched card concept was adopted by Charles Babbage to control his Analytical Engine and later by Herman Hollerith.



Fig. 1.8 : Joseph Marie Jacquard (1752 - 1834) and Jacquard's Loom

f. Difference engine

The first step towards the creation of computers was made by a mathematics professor, Charles Babbage. He dreamed of removing the human element from the calculations. He realised that all mathematical calculations can be broken up into simple operations which are constantly repeated and these operations could be carried out by an automatic machine. Charles Babbage started working on a

Difference Engine that could perform arithmetic calculations and print results automatically. In 1822, Babbage invented the Difference Engine to compile mathematical tables. On completing it, he conceived the idea of a better machine that could perform not just one mathematical task but any kind of calculation.

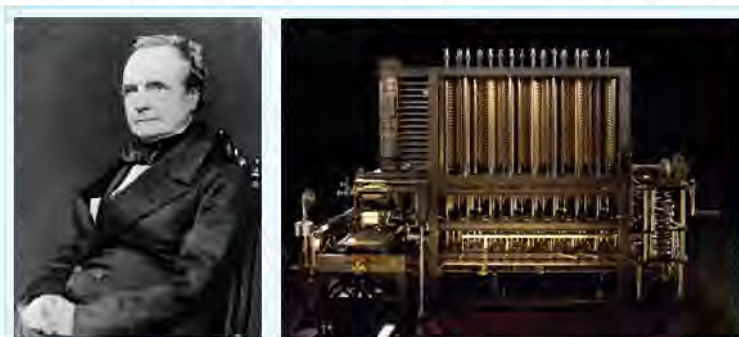


Fig. 1.9 : Charles Babbage (1791 - 1871) and Difference Engine

g. Analytical engine

In 1833, Charles Babbage started designing the Analytical Engine – the real predecessor of the modern day computer. Analytical Engine marks the development from arithmetic calculation to general-purpose computation. The Analytical Engine has many features found in the modern digital computer. The Engine had a ‘Store’ (memory) where numbers and intermediate results could be stored, and a separate ‘Mill’ (processor) where arithmetic processing could be performed. Its input/output devices were in the form of punched cards containing instructions. These instructions were written by Babbage’s assistant, Augusta Ada King, the first programmer in the world. Owing to the lack of technology at that time, the Analytical Engine was never built, but Babbage established the basic principles on which today’s modern computers work. Charles Babbage’s great inventions – the Difference Engine and the Analytical Engine earned Charles Babbage the title ‘Father of Computer’.

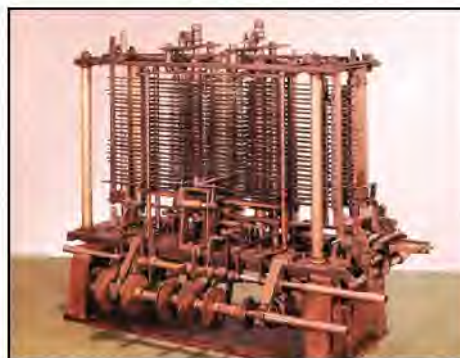


Fig. 1.10 : A model of Analytical Engine

h. Hollerith’s machine

In 1887, an American named Herman Hollerith fabricated the first electromechanical punched card tabulator that used punched cards for input, output and instructions.

The card had holes on them in a particular pattern, having special meaning for each kind of data. In 1880's, the US Census Bureau had huge amounts of data to tabulate. It would take at least ten years to analyse population statistics manually. Herman Hollerith's greatest breakthrough was his use of electricity to read, count and sort punched cards whose holes represented data. His machines were able to accomplish the task in one year. In 1896, Hollerith started the 'Tabulating Machine Corporation' which after a series of mergers, became International Business Machines (IBM) Corporation in 1924.



Fig. 1.11 : Herman Hollerith (1860 - 1929) and Hollerith Census Machine

i. Mark - I

In 1944, Howard Aiken, in collaboration with engineers at IBM, constructed a large automatic electromechanical computer. Aiken's machine, called the Harvard Mark I, based on Babbage's Analytical Engine, handled 23-decimal-place numbers and could perform all four arithmetic operations. It was preprogrammed to handle logarithms and trigonometric functions. Using Mark I, two numbers could be added in three to six seconds. For input and output, it used paper-tape readers, card readers, card punch and typewriters.

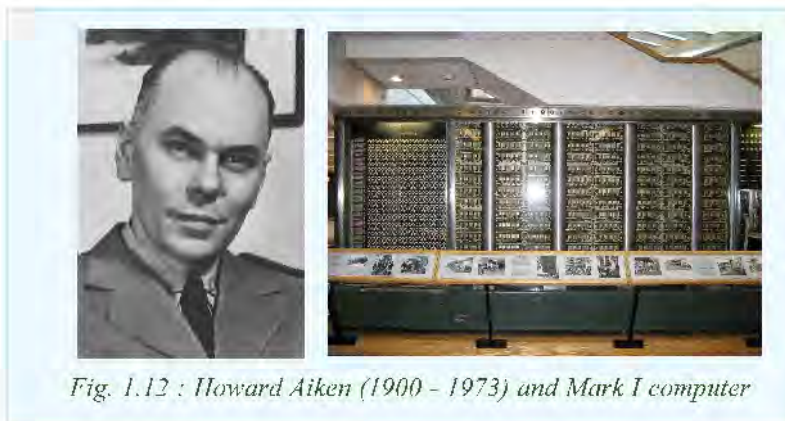


Fig. 1.12 : Howard Aiken (1900 - 1973) and Mark I computer

Check yourself



1. The Sumerian Number System is also known as _____.
2. What are the features of Hindu Arabic Number system?
3. How is the zero represented in the Babylonian Number System?
4. Who is the first programmer in the world?
5. The computing machine developed by Blaise Pascal is known as _____.

1.2 Generations of computers

The evolution of computer started from the 16th century, resulting in today's modern machines. It is distinguished into five generations of computers from the first programmable computer to the ones based on artificial intelligence. Each generation of computers is characterised by a major technological development that fundamentally changed the way computers operate, resulting smaller, cheaper, more powerful, more efficient and reliable computing devices. Based on various stages of development, computers can be divided into different generations. They are:

- First Generation Computers (1940 – 1956)
- Second Generation Computers (1956 – 1963)
- Third Generation Computers (1964 – 1971)
- Fourth Generation Computers (1971 – Present)
- Fifth Generation Computers (Present and beyond)

1.2.1 First generation computers (1940 – 1956)

The first generation computers were built using vacuum tubes. This generation implemented the stored program concept. A vacuum tube is a device controlling electric current through a vacuum in a sealed container. This cylindrical shaped container is made of thin transparent glass. The input was based on punched cards and paper tapes and output was displayed on printouts.

The first general purpose programmable electronic computer, the Electronic Numerical Integrator and Calculator (ENIAC) belongs to this generation. ENIAC was built by J. Presper Eckert and John V. Mauchly. The ENIAC was 30-50 feet long, weighed 30 tons, contained 18,000 vacuum tubes, 70,000 registers, 10,000 capacitors and required 1,50,000 watts of electricity. First generation computers

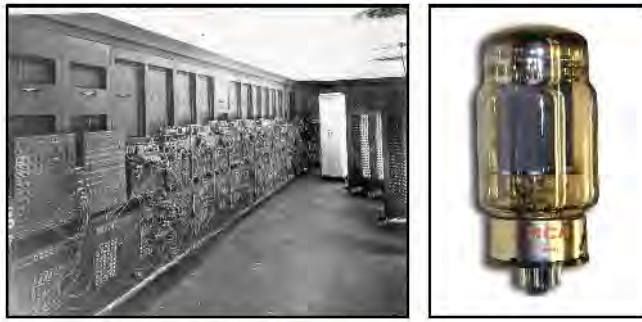


Fig. 1.13 : ENIAC and Vacuum tube

were too bulky in size, required a large room for installation and used to emit large amount of heat. Consequently, air-conditioner was a must for the proper working of computers.

Before ENIAC was completed, Von Neumann designed the Electronic Discrete Variable Automatic Computer (EDVAC) with a memory to hold both stored program as well as data. Eckert and Mauchly later developed the first commercially successful computer, the Universal Automatic Computer (UNIVAC), in 1952.

Von Neumann architecture

The mathematician John Von Neumann conceived a computer architecture which forms the core of nearly every computer system in use today. This architecture known as Von Neumann architecture consists of a central processing unit (CPU) containing arithmetic logic unit (ALU) and control unit (CU), input-output unit and a memory for storing data and instructions. This model implements the 'Stored Program Concept' in which the data and the instructions are stored in the memory.

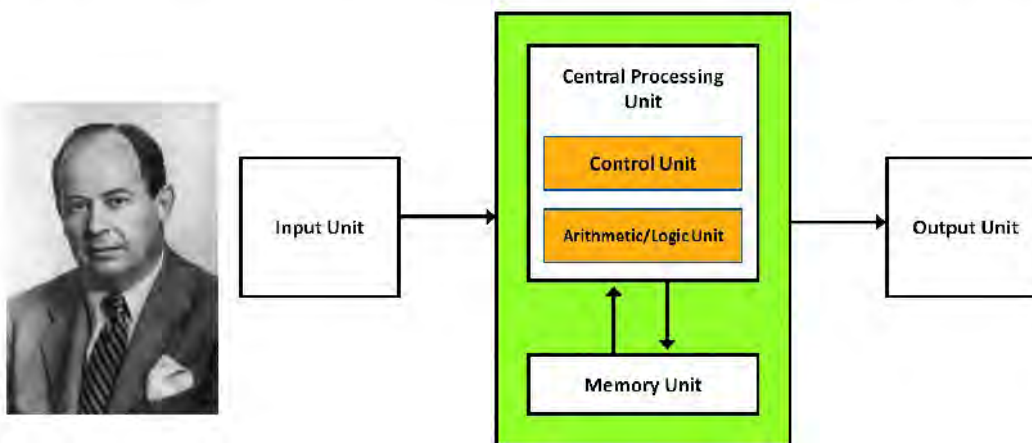


Fig. 1.14 : John Von Neumann (1903 - 1957) and Von Neumann architecture



In 1943, the British developed a secret code-breaking computer called Colossus to decode German messages. It was designed using vacuum tubes by the engineer Tommy Flowers. The Colossus's impact on the development of the computer industry was rather limited for two important reasons. First, Colossus was not a general-purpose computer; it was only designed to decode secret messages. Second, the existence of the machine was kept secret until 1970s. This deprived most of those involved with Colossus of credit for their pioneering advancements in electronic digital computing.



1.2.2 Second generation computers (1956 – 1963)

In second generation computers, vacuum tubes were replaced by transistors. It was developed at Bell Laboratories by John Bardeen, Walter Brattain and William Shockley in 1947. Replacing vacuum tubes with transistors, allowed computers to become smaller and more powerful and faster. They also became less expensive, required less electricity and emitted less heat. The manufacturing cost was also less.



Fig. 1.15 ; IBM 1401 and Transistors

It is in the second generation that the concept of programming language was developed. This generation used magnetic core memory and magnetic disk memory for primary and secondary storage respectively. Second-generation computers moved from cryptic binary machine language to symbolic or assembly languages. During second generation, many high level programming languages like FORTRAN and COBOL were introduced that allowed programmers to specify instructions in English like words. IBM 1401 and IBM 1620 are popular computers in this generation.

1.2.3 Third generation computers (1964 – 1971)

Third generation computers are smaller in size due to the use of integrated circuits (IC's). IC's or silicon chips that contained miniaturised transistors were developed by Jack Kilby, an engineer with Texas Instruments. IC drastically reduced the size and increased the speed and efficiency of computing. Multilayered printed circuits were developed and core memory was replaced by faster, solid state memories with large capacity.



Fig. 1.16 : IBM 360 and Integrated Circuit

This generation of computers had better processing speed, consumed less power and was less costly. Integrated circuits, improved secondary storage devices and new input/output devices like keyboards and monitors were introduced. Arithmetic and logical operations were performed in microseconds or even nanoseconds. These computers could run many different programs at one time with a central program that monitored the memory. The high level language BASIC which made programming easy was developed during this period. Computers for the first time became accessible to a mass audience because they were smaller and cheaper than their predecessors. Some computers in this generation are IBM 360 and IBM 370.



Moore's Law states that the number of transistors on integrated circuits doubles approximately every two years. The law is named after Gordon E Moore, who described the trend in 1965. He noted that the number of components in IC had doubled every year from 1958 to 1965. He predicted that the trend would continue 'for at least ten years'. His prediction has proven to be accurate. Although this trend continued for more than half a century, Moore's Law is considered only as an observation and not a physical or natural law.



1.2.4 Fourth generation computers (1971 onwards)

The computers that we use today belong to this generation. These computers use microprocessors and are called microcomputers. Microprocessor is a single chip which contains Large Scale of Integration (LSI) of electronic components like transistors, capacitors, resistors, etc. Due to the development of microprocessor, it is possible to place computer's Central Processing Unit (CPU) on a single chip. Because of microprocessors, the fourth generation includes more data processing capacity than third generation computers. Later LSI circuits were replaced by Very Large Scale Integrated (VLSI) circuits which further increased the scale of integration. The fourth generation computers are smaller in size and have faster accessing and processing speeds.

The computer which occupied a very large room in earlier days could now fit in a palm. These computers were interconnected to form computer networks, which eventually led to the development of the Internet. As computers became less costly and more user-friendly, large number of people began buying them for personal use. Some computers in this generation are IBM PC and Apple II.



Fig. 1.17 : VLSI Chip

1.2.5 Fifth generation computers (future)

Fifth generation computers are based on Artificial Intelligence (AI). AI is the ability to simulate human intelligence. Such intelligent systems are still in the development stage, though there are some applications, such as speech recognition, face recognition and robotic vision and movement that are already available.

AI is the branch of computer science concerned with developing computer programs (intelligent systems) for solving complex problems (which are normally done by human beings without any effort) by the application of process that are analogues to human reasoning process. The two most common AI programming languages are LISP and Prolog. The fifth-generation computing also aims at developing computing machines that respond to natural language input and are capable of learning and self-organisation.

Table 1.1 shows comparative features of five generations of computers.



The first processor Intel 4004 was developed in 1971 by Intel Corporation and consisted of 2,300 transistors integrated into a single IC. Some popular microprocessors and the number of transistors integrated in them are given below.

Processor	Transistor Count
Intel 8086	29,000
Motorola 68000 (used in Apple)	68,000
Intel Pentium	31,00,000
AMD K7	2,20,00,000
Core i7	73,10,00,000

Criteria	Generation				
	First	Second	Third	Fourth	Fifth
Technology	Vacuum Tube	Transistor	Integrated Circuit	Microprocessor	Artificial Intelligence
Operating System	None	None	Yes	Yes	Yes
Language	Machine	Assembly	High Level	High Level	High Level
Period	1940-1956	1956-1963	1964-1971	1971-Present	Present and Yet to come

Table 1.1 : Comparative features of five generations of computers

Check yourself



1. UNIVAC belongs to _____ generation..
2. What is meant by stored program concept?
3. Say True or False "Computers can understand only machine languages".
4. First generation computers are characterised by the use of _____.
5. What is the major technological advancement in the fourth generation computers?

1.3 Evolution of computing

Computing machines are used for processing, storing, and displaying information. The processing is done according to the instructions given to it. Early computers built during 1940's were only capable of performing series of single tasks, like a calculator. They were special-purpose systems programmed by rows of mechanical switches or by jumper wires on plug. The implementation of branching/looping statements, subroutine calls, etc. was not possible or was difficult. Later computers solved this problem by implementing John Von Neumann's revolutionary innovation the 'Stored Program Concept', which suggested storing data and programs in memory. The set of detailed instructions given to computer for executing a specific task is called a program.

Agusta Ada Lowelace

Augusta Ada King, Countess of Lowelace commonly known as Ada Lowelace, was an English mathematician and writer known for her work on Charles Babbage's early mechanical general-purpose computer, the Analytical Engine. Her notes on the engine included the first algorithm intended to be carried out by a machine. Because of this, she is often described as the world's first computer programmer.



Fig.1.18 : Agusta Ada Lowelace (1815 - 1852)

1.3.1 Programming languages

A programming language is an artificial language designed to communicate instructions to a computer. Programming languages can be used to create programs that control the behavior of a machine and/or to express algorithms.

The first programming language developed for use in computers was called machine language. Machine language consisted of strings of the binary digits 0 and 1. Introduction of this language improved the overall speed and efficiency of the programming process. This language had many drawbacks like difficulty in finding and rectifying programming errors and its machine dependency. The programmer also needed to have a good knowledge of the computer architecture.

To make programming easier, a new language with instructions consisting of English-like words instead of 0's and 1's, was developed. This language was called assembly language. Electronic Delay Storage Automatic Calculator (EDSAC) built during 1949 was the first to use assembly language. Although this made writing programs easier, it had limitations. It is specific to a given machine and the programs written in this language are not transferable from one machine to another.

This led to the development of new languages called high level languages which are machine independent and which used simple English-like words and statements. It allowed people having less knowledge of computer architecture to develop easy-to-understand programs. A-0 programming language developed by Rear Admiral Dr. Grace Hopper, in 1952, for UNIVAC-I computer is the first language of this type. FORTRAN developed by the team led by John Backus at IBM for IBM 704 machine and 'Lisp' developed by Tim Hart and Mike Levin at MIT are other examples.



Fig. 1.19 : Dr. Grace Hopper (1906-1992)

1.3.2 Algorithm and computer programs

A programmer cannot write the instruction to be followed by a computer, unless he/she knows how to solve the problem manually. In order to ensure that the program instructions are appropriate for solving the given problem, and are in the correct sequence, program instructions are to be planned before they are written. An effective tool for planning a computer program is an algorithm. An algorithm provides a step by step solution for a given problem. These steps can then be converted to machine instructions using a programming language.

1.3.3 Theory of computing

The theory of computation is the branch that deals with how efficiently problems can be solved based on computation models and related algorithms. In order to perform a rigorous study of computation, computer scientists work with a mathematical abstraction of computers called a model of computation. There are several models in use, but the most commonly examined is the 'Turing Machine' named after the famous computer scientist Alan Turing.

a. Contribution of Alan Turing

Alan M. Turing (1912 - 1954) was a British mathematician, logician, cryptographer and computer scientist. He made significant contributions to the development of computer science, by presenting the concepts of algorithm and computing with the help of his invention the 'Turing Machine', which is considered as a theoretical model of a general purpose computer. In 1950's, Alan Turing proposed to consider the question, 'Can machines think?' and later it turns out to be the foundation for the studies related to the computing machinery and intelligence. Turing proposed an imitation game which is later modified to 'Turing test' and it is considered to be the test for determining a machine's intelligence. Considering these contributions he is regarded as the Father of Modern Computer Science as well as Artificial Intelligence.

b. Turing machine

Turing machine is a model of a computer proposed by Alan Turing in 1936. It is conceived as an ideal model of 'computing'. Alan Turing reasoned that any computation that could be performed by a human involved writing down intermediate results, reading them back and carrying out actions that depend only on what has been read and the current state of things. Turing machine is a theoretical computing device that could print symbols on a paper tape in a manner that emulate a person following a series of logical instructions.

A Turing machine consists of an infinitely-long tape which acts like the memory in a computer. The cells on the tape are usually blank at the start and can be written with symbols. In this case, each cell can contain the symbols '0', '1' and ' ' (blank), and is thus said to be a 3-symbol Turing machine (refer Figure 1.22). At each step, the machine can read the symbol on the cell under the head, edit the symbol and move the tape left or right by one square so that the machine can read and edit the symbol in the neighbouring cells.



Fig. 1.20 : Alan Turing (1912 - 1954)



Fig. 1.21 : Turing machine



Fig. 1.22 : The head movement over tape

Any particular Turing machine is defined by a rule which specifies what the head should do at each step. The action of a Turing machine is determined by (a) the current state of the machine (b) the symbol in the cell currently being scanned by the head and (c) a table of transition rules, which serve as the 'program' for the machine.

In modern terms, the tape serves as the memory of the machine, while the read-write head is the memory bus through which data is accessed and updated by the machine. The initial arrangement of symbols of cells on the tape corresponds to the input given to the computer. The steps of the Turing machine correspond to the running of the computer. For a given input, each part of the rule specifies what 'operation' the machine should perform. Even though Turing machines are equivalent to modern electronic computers at a certain theoretical level, they differ in many details.



The Turing test

Alan Turing introduced the 'Turing test' in his paper titled 'Computing Machinery and Intelligence'. The 'Turing Test' involves a human interrogator and two contestants - a computer and a human. The interrogator converses with these contestants via computer terminals, without knowing the identity of the contestants. After a sufficiently long period of conversation, if the interrogator is unable to identify the computer, then the computer is said to have passed 'Turing test' and must be considered intelligent. Turing predicted that by 2000, computers would pass the test. There have been various programs that have demonstrated some amount of human like behaviour, but no computer has this far passed the Turing test.



Let us sum up

In this chapter, we briefly sketched the evolution of the number system and counting. We went through the development of computing machines and described the structure of the modern computing system. The evolution of computing was also discussed along with the different types of programming languages. The concepts of algorithms and computer programs were also discussed. The detailed description of generations of computers was also seen. Finally we discussed the theory of computation, in which the contributions of Alan Turing and the concept of 'Turing Machine' were outlined.



Learning outcomes

After the completion of this chapter the learner will be able to

- categorize the basic concept of computing milestones in history.
- sketch the modern computing machine.

- recognise the impact of John Von Neumann's Architecture in today's world.
- identify the pioneers of Computer Science.
- list the characteristics of computers in each generation.
- explain the contribution of Alan Turing and the concept of 'Turing Machine'.

Sample questions

Very short answer type

1. Which is the base of Mayan's Number System?
2. Greek Number System is known as _____.
3. Which was the first computer for basic arithmetic calculations?
4. Who invented logarithms?
5. What is the name of the machine developed by Blaise Pascal?
6. Who was the first programmer in the world?
7. Computing machines recognizes and operates in _____ language.
8. What does EDVAC stand for?
9. Give the name for a simple kind of theoretical computing machine.

Short answer type

1. Discuss the developments of the number system from the Egyptian to the Chinese Era.
2. Discuss the impact of Hindu-Arabic numeral system in the world.
3. Compare the Roman Number system and Mayan's Number System.
4. Discuss the features of Abacus.
5. Compare the Analytical Engine and Difference Engine of Charles Babbage.
6. Bring out the significance of Hollerith's machine.
7. What are the developments in computing machines that took place during the Second World War?
8. Discuss the evolution of computer languages.
9. Discuss the working of Turing Machine.

Long answer type

1. List out and explain the various generations of Computers.
2. Prepare a seminar report on evolution of positional number system.
3. Discuss the various computing machines emerged till 1900's.

Key concepts

- **Number systems**
 - Decimal, binary, octal, hexadecimal
- **Number conversions**
- **Binary arithmetic**
 - Addition, subtraction
- **Data representation**
 - Representation of integers and floating point numbers
 - Character representation: ASCII, EBCDIC, ISCII, UNICODE
 - Representation of audio, image and video data
- **Introduction to Boolean algebra**
 - Logic operators and logic gates
- **Basic postulates**
- **Basic theorems**
- **Circuit designing for simple Boolean expressions**
- **Universal gates**

Data Representation and Boolean Algebra

Computer is a machine that can handle different types of data items. We feed data such as numbers, characters, images, videos and sounds to a computer for processing. We know that computer is an electronic device functioning on the basis of two electric states - ON and OFF. All electronic circuits have two states - open and closed. The two-state operation is called binary operation. Hence, the data given to computer should also be in binary form. In this chapter we will discuss various methods for representing data such as numbers, characters, images, videos and sounds.

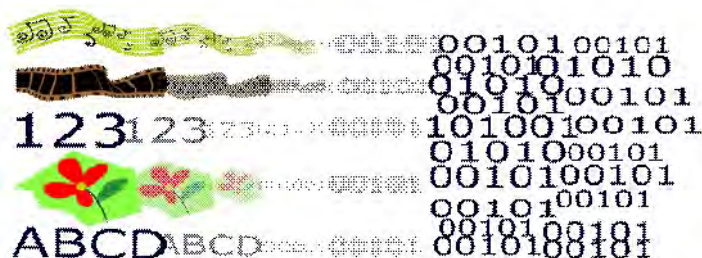


Fig. 2.1: External and internal form of data

Data representation is the method used internally to represent data in a computer.

Before discussing data representation of numbers, let us see what a number system is.

2.1 Number systems

A number is a mathematical object used to count, label and measure. A number system is a systematic way to represent numbers. The number system we use in our day to day life is the decimal number system that uses 10 symbols or digits. The number 289 is pronounced as two hundred and eighty nine and it consists of the symbols 2, 8 and 9. Similarly there are other number systems. Each has its own symbols and method for constructing a number. A number system has a unique base, which depends upon the number of symbols. The number of symbols used in a number system is called **base** or **radix** of a number system.

Let us discuss some of the number systems.

2.1.1 Decimal number system

The decimal number system involves ten symbols 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9 to form a number. Since there are ten symbols in this number system, its base is 10. Therefore, the decimal number system is also known as base-10 number system.

Consider two decimal numbers 743 and 347

743 \rightarrow seven hundred + four tens + three ones ($7 \times 10^2 + 4 \times 10^1 + 3 \times 10^0$)

347 \rightarrow three hundreds + four tens + seven ones ($3 \times 10^2 + 4 \times 10^1 + 7 \times 10^0$)

Here, place value (weight) of 7 in first number 743 is $10^2 = 100$. But weight of 7 in second number 347 is $10^0 = 1$. The weight of a digit depends on its relative position. Such a number system is known as **positional number system**. All positional number systems have a base and the place value of a digit is some power of this base.

Place value of each decimal digit is power of 10 ($10^0, 10^1, 10^2, \dots$). Consider a decimal number 5876.

This number can be written in expanded form as

Weight	10^3	10^2	10^1	10^0
Decimal Number	5	8	7	6

$$\begin{aligned}
 &= 5 \times 10^3 + 8 \times 10^2 + 7 \times 10^1 + 6 \times 10^0 \\
 &= 5 \times 1000 + 8 \times 100 + 7 \times 10 + 6 \times 1 \\
 &= 5000 + 800 + 70 + 6 \\
 &= 5876
 \end{aligned}$$

In the above example, the digit 5 has the maximum place value, $10^3 = 1000$ and 6 has the minimum place value, $10^0 = 1$. The digit with most weight is called Most Significant

Digit (MSD) and the digit with least weight is called Least Significant Digit (LSD). So in the above number MSD is 5 and LSD is 6.

Left most digit of a number is MSD and right most digit of a number is LSD

For fractional numbers weights are negative powers of 10 (10^{-1} , 10^{-2} , 10^{-3} , ...) for the digits to the right of decimal point. Consider another example 249.367

Weight	10^2	10^1	10^0	10^{-1}	10^{-2}	10^{-3}
Decimal Number	2	4	9	3	6	7
	MSD		(.)			LSD

$$\begin{aligned}
 &= 2 \times 10^2 + 4 \times 10^1 + 9 \times 10^0 + 3 \times 10^{-1} + 6 \times 10^{-2} + 7 \times 10^{-3} \\
 &= 2 \times 100 + 4 \times 10 + 9 \times 1 + 3 \times 0.1 + 6 \times 0.01 + 7 \times 0.001 \\
 &= 200 + 40 + 9 + 0.3 + 0.06 + 0.007 \\
 &= 249.367
 \end{aligned}$$

So far we have discussed a number system which uses 10 symbols. Now let us see the construction of other number systems with different bases.

2.1.2 Binary number system

A number system which uses only two symbols 0 and 1 to form a number is called binary number system. Bi means two. Base of this number system is 2. So it is also called base-2 number system. We use the subscript 2 to indicate that the number is in binary.

e.g. $(1101)_2$, $(101010)_2$, $(1101.11)_2$

Each digit of a binary number is called bit. A **bit** stands for **binary digit**.

The binary number system is also a positional number system where place value of each binary digit is power of 2. Consider an example $(1101)_2$. This binary number can be written in expanded form as shown below:

Weight	2^3	2^2	2^1	2^0
Binary Number	1	1	0	1
	MSB			LSB

$$\begin{aligned}
 &= 1 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 \\
 &= 1 \times 8 + 1 \times 4 + 0 \times 2 + 1 \times 1 \\
 &= 8 + 4 + 0 + 1 \\
 &= 13
 \end{aligned}$$

The right most bit in a binary number is called Least significant Bit (**LSB**). The leftmost bit in a binary number is called Most significant Bit (**MSB**).

The binary number 1101 is equivalent to the decimal number 13. The number 1101 also exists in the decimal number system. But it is interpreted as one thousand one hundred and one. To avoid this confusion, base must be specified in all number systems other than decimal number system. The general format is

$$(\text{Number})_{\text{base}}$$

This notation helps to differentiate numbers of different bases. So a binary number must be represented with base 2 as $(1101)_2$ and it is read as “one one zero one to the base two”.

If no base is given in a number, it will be considered as decimal. In other words, specifying the base is not compulsory in decimal number.

For fractional numbers, weights are negative powers of 2 ($2^{-1}, 2^{-2}, 2^{-3}, \dots$) for the digits to the right of the binary point. Consider an example $(111.011)_2$

Weight	2^2	2^1	2^0	2^{-1}	2^{-2}	2^{-3}
Binary Number	1	1	1	0	1	1

MSB

(.)

LSB

$$= 1 \times 2^2 + 1 \times 2^1 + 1 \times 2^0 + 0 \times 2^{-1} + 1 \times 2^{-2} + 1 \times 2^{-3}$$

$$= 1 \times 4 + 1 \times 2 + 1 \times 1 + 0 \times \frac{1}{2} + 1 \times \frac{1}{4} + 1 \times \frac{1}{8}$$

$$= 4 + 2 + 1 + 0 + 0.25 + 0.125$$

$$= 7.375$$

Importance of binary numbers in computers

We have seen that binary number system is based on two digits 1 and 0. The electric state ON can be represented by 1 and the OFF state by 0 as in Figure 2.2. Because of this, computer uses binary number system as the basic number system for data representation.

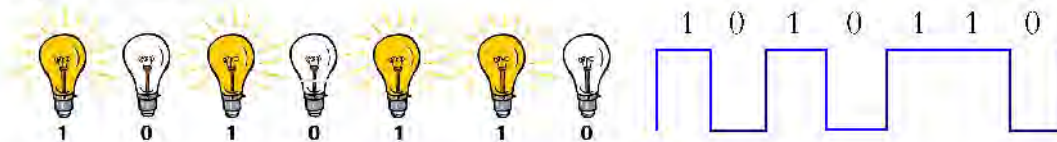


Fig. 2.2 : Digital representation of ON and OFF

2.1.3 Octal number system

A number system which uses eight symbols 0, 1, 2, 3, 4, 5, 6 and 7 to form a number is called octal number system. Octa means eight, hence this number system is called

octal. Base of this number system is 8 and hence it is also called base-8 number system. Consider an example $(236)_8$. Weight of each digit is power of 8 ($8^0, 8^1, 8^2, 8^3, \dots$). The number $(236)_8$ can be written in expanded form as

Weight	8^2	8^1	8^0
Octal Number	2	3	6

$$\begin{aligned}
 &= 2 \times 8^2 + 3 \times 8^1 + 6 \times 8^0 \\
 &= 2 \times 64 + 3 \times 8 + 6 \times 1 \\
 &= 128 + 24 + 6 \\
 &= 158
 \end{aligned}$$

For fractional numbers weights are negative powers of 8, i.e. ($8^{-1}, 8^{-2}, 8^{-3}, \dots$) for the digits to the right of the octal point. Consider an example $(172.4)_8$

Weight	8^2	8^1	8^0	8^{-1}
Octal Number	1	7	2	4

$$\begin{aligned}
 &= 1 \times 8^2 + 7 \times 8^1 + 2 \times 8^0 + 4 \times 8^{-1} \\
 &= 64 + 56 + 2 + 4 \times \frac{1}{8} \\
 &= 122 + 0.5 \\
 &= 122.5
 \end{aligned}$$

2.1.4 Hexadecimal number system

A number system which uses 16 symbols (0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E and F) to form a number is called hexadecimal number system. Base of this number system is 16 as there are sixteen symbols in this number system. Hence this number system is also called base-16 number system.

In this system, the symbols A, B, C, D, E and F are used to represent the decimal numbers 10, 11, 12, 13, 14 and 15 respectively. The hexadecimal digit and their equivalent decimal numbers are shown below.

Hexadecimal	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
Decimal	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Consider a hexadecimal number $(12AF)_{16}$. Weights of each digit is power of 16 ($16^0, 16^1, 16^2, \dots$).

This number can be written in expanded form as shown below:

Weight	16^3	16^2	16^1	16^0
Hexadecimal Number	1	2	A	F

$$\begin{aligned}
 &= 1 \times 16^3 + 2 \times 16^2 + 10 \times 16^1 + 15 \times 16^0 \\
 &= 1 \times 4096 + 2 \times 256 + 10 \times 16 + 15 \times 1 \\
 &= 4096 + 512 + 160 + 15 \\
 &= 4783
 \end{aligned}$$

For fractional numbers, weights are some negative power of 16 (16^{-1} , 16^{-2} , 16^{-3} , ...) for the digits to the right of the hexadecimal point. Consider an example $(2D.4)_{16}$

Weight	16^1	16^0	16^{-1}
Hexadecimal	2	D	4

$$\begin{aligned}
 &= 2 \times 16^1 + 13 \times 16^0 + 4 \times \frac{1}{16} \\
 &= 32 + 13 + 0.25 \\
 &= 45.25
 \end{aligned}$$

Table 2.1 shows the base and symbols used in different number systems:

Number System	Base	Symbols used
Binary	2	0, 1
Octal	8	0, 1, 2, 3, 4, 5, 6, 7
Decimal	10	0, 1, 2, 3, 4, 5, 6, 7, 8, 9
Hexadecimal	16	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F

Table 2.1 : Number systems with base and symbols

Importance of octal and hexadecimal number systems

As we have discussed, digital hardware uses the binary number system for its operations and data. Representing numbers and operations in binary form requires too many bits and needs lot of effort. With octal, the bits are grouped in threes (because $2^3 = 8$) and with hexadecimal, the bits are grouped in four (because $2^4 = 16$) and these groups are replaced with the respective octal or hexadecimal symbol. This conversion processes of binary numbers to octal and hexadecimal number systems and vice versa are very easy. This short-hand notation is widely used in the design and operations of electronic circuits.

Check yourself

1. Number of symbols used in a number system is called ____.
2. Pick invalid numbers from the following
i) $(10101)_8$ ii) $(123)_4$ iii) $(768)_8$ iv) $(ABC)_{16}$
3. Define the term 'bit'.
4. Find MSD in the decimal number 7854.25.
5. The base of hexadecimal number system is ____.

2.2 Number conversions

After having learnt the various number systems, let us now discuss how to convert the numbers of one base to the equivalent numbers in other bases. There are different types of number conversions like decimal to binary, binary to decimal, decimal to octal etc. This section discusses how to convert one number system to another.

2.2.1 Decimal to binary conversion

The method of converting decimal number to binary number is by repeated division. In this method the decimal number is successively divided by 2 and the remainders are recorded. The binary equivalent is obtained by grouping all the remainders, with the last remainder being the Most Significant Bit (MSB) and first remainder being the Least Significant Bit (LSB). In all these cases the remainders will be either 0 or 1 (binary digit).

Examples:

Find binary equivalent of decimal number 25.

2	25	Remainders	
2	12	1	↑ LSB
2	6	0	
2	3	0	
2	1	1	
	0	1	MSB

$$(25)_{10} = (11001)_2$$

Find binary equivalent of $(80)_{10}$.

2	80	Remainders	
2	40	0	↑ LSB
2	20	0	
2	10	0	
2	5	0	
2	2	1	
2	1	0	↑ MSB
	0	1	

$$(80)_{10} = (1010000)_2$$

Hint: Binary equivalent of an odd decimal number ends with 1 and binary of even decimal number ends with zero.

Converting decimal fraction to binary

To convert a fractional decimal number to binary, we use the method of repeated multiplication by 2. At first the decimal fraction is multiplied by 2. The integer part of the answer will be the MSB of binary fraction. Again the fractional part of the answer is multiplied by 2 to obtain the next significant bit of binary fraction. The procedure is continued till the fractional part of product is zero or a desired precision is obtained.

Example: Convert 0.75 to binary.

	$0.75 \times 2 = 1.50$
1	$.50 \times 2 = 1.00$
1	$.00$

$(0.75)_{10} = (0.11)_2$

Example: Convert 0.625 to binary.

	$0.625 \times 2 = 1.25$
1	$.25 \times 2 = 0.50$
0	$.50 \times 2 = 1.00$
1	$.00$

$(0.625)_{10} = (0.101)_2$

Example: Convert 15.25 to binary.

Convert 15 to binary

2	15	Remainders
2	7	1
2	3	1
2	1	1
	0	1

Convert 0.25 to binary

	$0.25 \times 2 = 0.50$
0	$.50 \times 2 = 1.00$
1	$.00$

$(15.25)_{10} = (1111.01)_2$

2.2.2 Decimal to octal conversion

The method of converting decimal number to octal number is also by repeated division. In this method the number is successively divided by 8 and the remainders

are recorded. The octal equivalent is obtained by grouping all the remainders, with the last remainder being the MSD and first remainder being the LSD. Remainders will be 0, 1, 2, 3, 4, 5, 6 or 7.

Example: Find octal equivalent of decimal number 125.

8	125	Remainders	
8	15	5	↑ LSD
8	1	7	
	0	1	MSD

$$(125)_{10} = (175)_8$$

Example: Find octal equivalent of $(400)_{10}$.

8	400	Remainders	
8	50	0	↑
8	6	2	
	0	6	

$$(400)_{10} = (620)_8$$

2.2.3 Decimal to hexadecimal conversion

The method of converting decimal number to hexadecimal number is also by repeated division. In this method, the number is successively divided by 16 and the remainders are recorded. The hexadecimal equivalent is obtained by grouping all the remainders, with the last remainder being the Most Significant Digit (MSD) and first remainder being the Least Significant Digit (LSD). Remainders will be 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E or F.

Example: Find hexadecimal equivalent of decimal number 155.

16	155	Remainders	
16	9	11 (B)	↑ → LSD
	0	9	→ MSD

$$(155)_{10} = (9B)_{16}$$

Example: Find hexadecimal equivalent of 380.

16	380	Remainders	
16	23	12 (C)	↑
16	1	7	
	0	1	

$$(380)_{10} = (17C)_{16}$$

2.2.4 Binary to decimal conversion

A binary number can be converted into its decimal equivalent by summing up the product of each bit and its weight. Weights are some power of 2 ($2^0, 2^1, 2^2, 2^3, \dots$).

Example: Convert $(11011)_2$ to decimal.

$$\begin{aligned}(11011)_2 &= 1 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0 \\ &= 16 + 8 + 2 + 1 \\ &= 27\end{aligned}$$

Weight	2^4	2^3	2^2	2^1	2^0
Bit	1	1	0	1	1

$$(11011)_2 = (27)_{10}$$

Example: Convert $(1100010)_2$ to decimal.

Weight	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Bit	1	1	0	0	0	1	0

$$\begin{aligned}(1100010)_2 &= 1 \times 2^6 + 1 \times 2^5 + 0 \times 2^4 + 0 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 0 \times 2^0 \\ &= 64 + 32 + 2 \\ &= 98\end{aligned}$$

$$(1100010)_2 = (98)_{10}$$

Table 2.2 may help us to find powers of 2.

2^{10}	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
1024	512	256	128	64	32	16	8	4	2	1

Table 2.2 : Powers of 2

Converting binary fraction to decimal

A binary fraction number can be converted into its decimal equivalent by summing up the product of each bit and its weight. Weights of binary fractions are negative powers of 2 ($2^{-1}, 2^{-2}, 2^{-3}, \dots$) for the digits after the binary point.

Example: Convert $(0.101)_2$ to decimal.

$$\begin{aligned}(0.101)_2 &= 1 \times 2^{-1} + 0 \times 2^{-2} + 1 \times 2^{-3} \\ &= 0.5 + 0 + 0.125 \\ &= 0.625\end{aligned}$$

Weight	2^{-1}	2^{-2}	2^{-3}
Bit	1	0	1

$$(0.101)_2 = (0.625)_{10}$$

Example: Convert $(1010.11)_2$ to decimal.

$$\begin{aligned}(1010)_2 &= 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 0 \times 2^0 \\ &= 8 + 0 + 2 + 0 \\ &= 10\end{aligned}$$

$$(1010)_2 = (10)_{10}$$

Weight	2^3	2^2	2^1	2^0
Bit	1	0	1	0

$$\begin{aligned}
 (0.11)_2 &= 1 \times 2^{-1} + 1 \times 2^{-2} \\
 &= 0.5 + 0.25 \\
 &= 0.75
 \end{aligned}
 \quad (0.11)_2 = (0.75)_{10}$$

Weight	2^{-1}	2^{-2}
Bit	1	1

$$(1010.11)_2 = (10.75)_{10}$$

Table 2.3 shows some negative powers of 2.

2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}
0.5	0.25	0.125	0.0625	0.03125

Table 2.3 : Negative powers of 2

2.2.5 Octal to decimal conversion

An octal number can be converted into its decimal equivalent by summing up the product of each octal digit and its weight. Weights are some powers of 8 ($8^0, 8^1, 8^2, 8^3, \dots$).

Example: Convert $(157)_8$ to decimal.

$$\begin{aligned}
 (157)_8 &= 1 \times 8^2 + 5 \times 8^1 + 7 \times 8^0 \\
 &= 64 + 40 + 7 \\
 &= 111
 \end{aligned}$$

Weight	8^2	8^1	8^0
Octal digit	1	5	7

$$(157)_8 = (111)_{10}$$

Example: Convert $(1005)_8$ to decimal.

$$\begin{aligned}
 (1005)_8 &= 1 \times 8^3 + 0 \times 8^2 + 0 \times 8^1 + 5 \times 8^0 \\
 &= 512 + 5 \\
 &= 517
 \end{aligned}$$

Weight	8^3	8^2	8^1	8^0
Octal digit	1	0	0	5

$$(1005)_8 = (517)_{10}$$

2.2.6 Hexadecimal to decimal conversion

An hexadecimal number can be converted into its decimal equivalent by summing up the product of each hexadecimal digit and its weight. Weights are powers of 16 ($16^0, 16^1, 16^2, \dots$).

Example: Convert $(AB)_{16}$ to decimal.

$$\begin{aligned}
 (AB)_{16} &= 10 \times 16^1 + 11 \times 16^0 \\
 &= 160 + 11 \\
 &= 171
 \end{aligned}$$

Weight	16^1	16^0
Hexadecimal digit	A	B

$$A = 10 \quad B = 11$$

$$(AB)_{16} = (171)_{10}$$

Example: Convert $(2D5)_{16}$ to decimal.

$$\begin{aligned}(2D5)_{16} &= 2 \times 16^2 + 13 \times 16^1 + 5 \times 16^0 \\ &= 512 + 208 + 5 \\ &= 725\end{aligned}$$

Weight	16^2	16^1	16^0
Hexadecimal digit	2	D	5

$$D = 13$$

$$(2D5)_{16} = (725)_{10}$$

2.2.7 Octal to binary conversion

An octal number can be converted into binary by converting each octal digit to its 3 bit binary equivalent. Eight possible octal digits and their binary equivalents are listed in Table 2.4.

Octal Digit	0	1	2	3	4	5	6	7
Binary Equivalent	000	001	010	011	100	101	110	111

Table 2.4 : Binary equivalent of octal digit

Example: Convert $(437)_8$ to binary.

3-bit binary equivalents of each octal digit are

$$\begin{array}{ccc} 4 & 3 & 7 \\ \downarrow & \downarrow & \downarrow \\ 100 & 011 & 111 \end{array}$$

$$(437)_8 = (100011111)_2$$

Example: Convert $(7201)_8$ to binary.

3-bit binary equivalents of each octal digits are

$$\begin{array}{cccc} 7 & 2 & 0 & 1 \\ \downarrow & \downarrow & \downarrow & \downarrow \\ 111 & 010 & 000 & 001 \end{array}$$

$$(7201)_8 = (111010000001)_2$$

2.2.8 Hexadecimal to binary conversion

A hexadecimal number can be converted into binary by converting each hexadecimal digit to its 4 bit binary equivalent. Sixteen possible hexadecimal digits and their binary equivalents are listed in Table 2.5.

Example: Convert $(AB)_{16}$ to binary.

4-bit binary equivalents of each hexadecimal digit are

$$\begin{array}{cc}
 A & B \\
 \downarrow & \downarrow \\
 1010 & 1011 \\
 (AB)_{16} = (10101011)_2
 \end{array}$$

Example: Convert $(2F15)_{16}$ to binary.

4-bit binary equivalents of each hexadecimal digit are

$$\begin{array}{cccc}
 2 & F & 1 & 5 \\
 \downarrow & \downarrow & \downarrow & \downarrow \\
 0010 & 1111 & 0001 & 0101 \\
 (2F15)_{16} = (10111100010101)_2
 \end{array}$$

2.2.9 Binary to octal conversion

A binary number can be converted into its octal equivalent by grouping binary digits to group of 3 bits and then each group is converted to its octal equivalent. Start grouping from right to left.

Example: Convert $(101100111)_2$ to octal.

We can group above binary number 101100111 from right as shown below.

$$\begin{array}{ccc}
 101 & 100 & 111 \\
 \downarrow & \downarrow & \downarrow \\
 5 & 4 & 7 \\
 (101100111)_2 = (547)_8
 \end{array}$$

Example: Convert $(10011000011)_2$ to octal.

We can group above binary number 10011000011 from right as shown below.

$$\begin{array}{cccc}
 010 & 011 & 000 & 011 \\
 \downarrow & \downarrow & \downarrow & \downarrow \\
 2 & 3 & 0 & 3 \\
 (10011000011)_2 = (2303)_8
 \end{array}$$

After grouping, if the left most group has no 3 bits, then add leading zeros to form 3 bit binary.

Hexa decimal	Binary equivalent
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
A	1010
B	1011
C	1100
D	1101
E	1110
F	1111

Table 2.5 :
Binary equivalent of hexadecimal digits

2.2.10 Binary to hexadecimal conversion

A binary number can be converted into its hexadecimal equivalent by grouping binary digits to group of 4 bits and then each group is converted to its hexadecimal equivalent. Start grouping from right to left.

Example: Convert $(101100111010)_2$ to hexadecimal.

We can group the given binary number 101100111010 from right as shown below:

$$\begin{array}{ccc} 1011 & 0011 & 1010 \\ \downarrow & \downarrow & \downarrow \\ B & 3 & A \end{array}$$

$$(101100111010)_2 = (B3A)_{16}$$

Example: Convert $(110111100001100)_2$ to hexadecimal.

We can group the given binary number 110111100001100 from right as shown below:

After grouping, if the left most group has no 4 bits, then add leading zeros to form 4 bit binary.

$$\begin{array}{cccc} 0110 & 1111 & 0000 & 1100 \\ \downarrow & \downarrow & \downarrow & \downarrow \\ 6 & F & 0 & C \end{array}$$

$$(110111100001100)_2 = (6F0C)_{16}$$

2.2.11 Octal to hexadecimal conversion

Conversion of an octal number to hexadecimal number is a two step process. Octal number is first converted into binary. This binary equivalent is then converted into hexadecimal.

Example: Convert $(457)_8$ to hexadecimal equivalent.

First convert $(457)_8$ into binary.

$$\begin{array}{ccc} (457)_8 = & 4 & 5 & 7 \\ & \downarrow & \downarrow & \downarrow \\ & 100 & 101 & 111 \\ & = (100101111)_2 \end{array}$$

Then convert $(100101111)_2$ into hexadecimal as follows:

$$\begin{array}{ccc} (100101111)_2 = & 0001 & 0010 & 1111 \\ & \downarrow & \downarrow & \downarrow \\ & = 1 & 2 & F \\ & = (12F)_{16} \end{array}$$

$$(457)_8 = (12F)_{16}$$

2.2.12 Hexadecimal to octal conversion

Conversion of an hexadecimal to octal number is also a two step process. Hexadecimal number is first converted into binary. This binary equivalent is then converted into octal.

Example: Convert $(A2D)_{16}$ into octal equivalent.

First convert $(A2D)_{16}$ into binary.

$$\begin{aligned} (A2D)_{16} &= \begin{array}{ccc} A & 2 & D \\ \downarrow & \downarrow & \downarrow \\ 1010 & 0010 & 1101 \end{array} \\ &= (101000101101)_2 \end{aligned}$$

Then convert $(101000101101)_2$ into octal as follows:

$$\begin{aligned} (101000101101)_2 &= \begin{array}{cccc} 101 & 000 & 101 & 101 \\ \downarrow & \downarrow & \downarrow & \downarrow \\ 5 & 0 & 5 & 5 \end{array} \\ &= (5055)_8 \end{aligned}$$

$$(A2D)_{16} = (5055)_8$$

Table 2.6 shows procedures for various number conversions.

Conversion	Procedure
Decimal to Binary	Repeated division by 2 and grouping the remainders
Decimal to Octal	Repeated division by 8 and grouping the remainders
Decimal to Hexadecimal	Repeated division by 16 and grouping the remainders
Binary to Decimal	Multiply binary digit by place value (power of 2) and find their sum
Octal to Decimal	Multiply octal digit by place value (power of 8) and find their sum
Hexadecimal to Decimal	Multiply hexadecimal digit by place value (power of 16) and find their sum
Octal to Binary	Converting each octal digit to its 3 bit binary equivalent
Hexadecimal to Binary	Converting each hexadecimal digit to its 4 bit binary equivalent
Binary to Octal	Grouping binary digits to group of 3 bits from right to left
Binary to Hexadecimal	Grouping binary digits to group of 4 bits from right to left
Octal to Hexadecimal	Convert octal to binary and then binary to hexadecimal
Hexadecimal to Octal	Convert hexadecimal to binary and then binary to octal

Table 2.6 : Procedure for number conversions

Check yourself



- 1 Convert the decimal number 31 to binary.
- 2 Find decimal equivalent of $(10001)_2$
- 3 If $(x)_8 = (101011)_2$, then find x.
- 4 Fill in the blanks:
 - a) $(\quad)_2 = (AB)_{16}$
 - b) $(\text{---D---})_{16} = (1010\text{---}1000)_2$
 - c) $0.25_{10} = (\quad)_2$
- 5 Find the largest number in the list
 (i) $(1001)_2$ (ii) $(A)_{16}$ (iii) $(10)_8$ (iv) $(11)_{10}$

2.3 Binary arithmetic

As in the case of decimal number system, arithmetic operations are performed in binary number system. When we give instruction to add two decimal numbers, the computer actually adds their binary equivalents. Let us see how binary addition and subtraction are carried out.

2.3.1 Binary addition

The rules for adding two bits are as follows:

A	B	Sum	Carry
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

Note that a carry bit 1 is created only when two ones are added. If three ones are added (i.e. $1+1+1$), then the sum bit is 1 with a carry bit 1.

Example: Find sum of binary numbers 1011 and 1001.

$$\begin{array}{r} 1011 + \\ 1001 \\ \hline 10100 \end{array}$$

Example: Find sum of binary numbers 110111 and 10011.

$$\begin{array}{r} 110111 + \\ 100110 \\ \hline 1011101 \end{array}$$

2.3.2 Binary subtraction

The rules for subtracting a binary digit from another digit are as follows.

A	B	Difference	Borrow
0	0	0	0
0	1	1	1
1	0	1	0
1	1	0	0

Note that when 1 is subtracted from 0 the difference is 1, but 1 is borrowed from immediate left bit of first number. The above rules can be used only when a small binary number is subtracted from a large binary number.

Example: Subtract $(10101)_2$ from $(11111)_2$.

$$\begin{array}{r} 11111 \\ - 10101 \\ \hline 01010 \end{array}$$

Example: Subtract $(10111)_2$ from $(101000)_2$.

$$\begin{array}{r} 101000 \\ - 10111 \\ \hline 10001 \end{array}$$

2.4 Data representation

Computer uses a fixed number of bits to represent a piece of data which could be a number, a character, image, sound, video etc. Data representation is the method used internally to represent data in a computer. Let us see how various types of data can be represented in computer memory.

2.4.1 Representation of numbers

Numbers can be classified into integer numbers and floating point numbers. Integers are whole numbers or numbers without any fractional part. A floating point number or a real number is a number with fractional part. These two numbers are treated differently in computer memory. Let us see how integers are represented.

a. Representation of integers

There are three methods for representing an integer number in computer memory. They are

- Sign and magnitude representation
- 1's complement representation
- 2's complement representation

The following data representation methods are based on 8 bit word length.

A **word** is basically a fixed-sized group of bits that are handled as a unit by a processor. Number of bits in a word is called **word length**. The word length is the choice of computer designer and some popular word lengths are 8, 16, 32 and 64.

i. Sign and magnitude representation

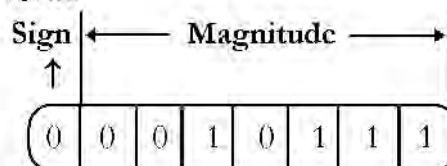
In this method, first bit from left (MSB) is used for representing sign of integer and remaining 7-bits are used for representing magnitude of integer. For negative integers sign bit is 1 and for positive integers sign bit is 0. Magnitude is represented as 7-bit binary equivalent of the integer.

Example: Represent + 23 in sign and magnitude form.

Number is positive, so first bit (MSB) is 0.

7 bit binary equivalent of $23 = (0010111)_2$

So + 23 can be represented as $(00010111)_2$

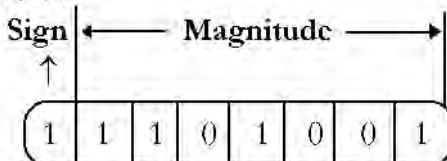


Example: Represent -105 in sign and magnitude form.

Number is negative, so first bit (MSB) is 1

7 bit binary equivalent of $105 = (1101001)_2$

So -105 can be represented as $(11101001)_2$



Note: In this method an 8 bit word can represent $2^8-1=255$ numbers (i.e. -127 to +127). Similarly, a 16 bit word can represent $2^{16}-1=65535$ numbers (i.e. -32767 to +32767). So, an n -bit word can represent 2^n-1 numbers i.e., $-(2^{n-1}-1)$ to $+(2^{n-1}-1)$. The integer 0 can be represented in two ways: $+0 = 00000000$ and $-0 = 10000000$.

ii. 1's complement representation

In this method, first find binary equivalent of absolute value of integer. If number of digits in binary equivalent is less than 8, provide zero(s) at the left to make it 8-bit form. 1's complement of a binary number is obtained by replacing every 0 with 1 and every 1 with 0. Some binary numbers and the corresponding 1's complements are given below:

Binary Number	1's Complement
11001	00110
10101	01010

If the number is negative it is represented as 1's complement of 8-bit form binary. If the number is positive, the 8-bit form binary equivalent itself is the 1's complement representation.

Example: Represent -119 in 1's complement form.

$$\text{Binary of } 119 \text{ in 8-bit form} = (01110111)_2$$

$$-119 \text{ in 1's complement form} = (10001000)_2$$

Example: Represent +119 in 1's complement form.

$$\text{Binary of } 119 \text{ in 8-bit form} = (01110111)_2$$

$$+119 \text{ in 1's complement form} = (01110111)_2$$

(No need to find 1's complement, since the number is positive)

Note: In this representation if first bit (MSB) is 0 then number is positive and if MSB is 1 then number is negative. So 8 bit word can represent integers from -127 (represented as 10000000) to +127 (represented as 01111111). Here also integer 0 can be represented in two ways: $+0 = 00000000$ and $-0 = 11111111$. An n -bit word can represent $2^n - 1$ numbers i.e. $-(2^{n-1} - 1)$ to $+(2^{n-1} - 1)$.

iii. 2's complement representation

In this method, first find binary equivalent of absolute value of integer and write it in 8-bit form. If the number is negative, it is represented as 2's complement of 8-bit form binary. If the number is positive, 8-bit form binary itself is the representation. 2's complement of a binary number is calculated by adding 1 to its 1's complement.

For example, let us find the 2's complement of $(10101)_2$.

$$1's \text{ complement of } (10101)_2 = (01010)_2$$

$$\begin{aligned} \text{So } 2's \text{ complement of } (10101)_2 &= 01010 + \\ &\quad 1 \\ &= (01011)_2 \end{aligned}$$

Example: Represent -38 in 2's complement form.

$$\text{Binary of } 38 \text{ in 8-bit form} = (00100110)_2$$

$$\begin{aligned} -38 \text{ in 2's complement form} &= 11011001 + \\ &\quad 1 \\ &= (11011010)_2 \end{aligned}$$

Example: Represent +38 in 2's complement form.

$$\text{Binary of } 38 \text{ in 8-bit form} = (00100110)_2$$

$$+38 \text{ in 2's complement form} = (00100110)_2 \text{ (No need to find 2's complement)}$$

Note: In this representation if first bit (MSB) is 0 then number is positive and if MSB is 1 then number is negative. Here integer 0 has only one way of representation and is 00000000. So an 8 bit word can represent integers from -128 (represented as 10000000) to +127 (represented as 01111111). It is the most common integer representation. An n -bit word can represent 2^n numbers $-(2^{n-1})$ to $+(2^{n-1} - 1)$. Table 2.7 shows the comparison of different representation methods of integers in 8-bit word length.

Features	Sign & Magnitude	1's Complement	2's Complement	Remarks
Range	-127 to +127	-127 to +127	-128 to +127	Range is more in 2's complement
Total Numbers	255	255	256	
Representation of integer 0	Two ways of representation	Two ways of representation	Only one way of representation	In 2's complement there is no ambiguity in 0 representation
Representation of positive integers	Binary equivalent of integer in 8 bit form	Binary equivalent of integer in 8 bit form	Binary equivalent of integer in 8 bit form	All three forms are same.
Representation of negative integers	Sign bit 1 and magnitude is represented in 7 bit binary form	Find 1's complement of 8 bit form binary	Find 2's complement of 8 bit form binary	For all negative numbers MSB is 1

Table 2.7 : Comparison for representation of integers in 8-bit word length

Subtraction using complements

We have discussed how to subtract a binary number from another binary number. But to design and implement an electronic circuit for this method of subtraction is really complex and difficult. Circuitry for binary addition is simpler. So it is better if we can subtract through addition. For that we use the concept of complements. There are two methods of subtraction using complements.

Subtraction using 1's complement

The steps for subtracting a smaller binary number from a larger binary number are:

- Step 1:** Add 0s to the left of smaller number, if necessary, to make two numbers with same number of bits.
- Step 2:** Find 1's complement of subtrahend (Number to be subtracted, here small number)
- Step 3:** Add the complement with minuend (Number from which subtracting, here larger number)
- Step 4:** Add the carry 1 to the sum to get the answer.

Example: Subtract 100_2 from 1010_2 using 1's complement.

At first find 1's complement of 0100 and it is 1011



To compare the three types of representations let us consider the following table. For clarity and easy illustration, 4-bits are used to represent the numbers in this table.

Number	Sign & Magnitude	1's Complement	2's Complement
-8	Not possible	Not possible	1000
-7	1111	1000	1001
-6	1110	1001	1010
-5	1101	1010	1011
-4	1100	1011	1100
-3	1011	1100	1101
-2	1010	1101	1110
-1	1001	1110	1111
0	1000 or 0000	0000 or 1111	0000
1	0001	0001	0001
2	0010	0010	0010
3	0011	0011	0011
4	0100	0100	0100
5	0101	0101	0101
6	0110	0110	0110
7	0111	0111	0111

From this table, it is clear that the MSB of a binary number indicates the sign of the corresponding decimal number irrespective of the representation. That is, if the MSB is 1, the number is negative and if it is 0, the number is positive. The table also shows that only 2's complement method can represent the maximum numbers for a given number of bits. This fact reveals that, a number below -7 and above +7 cannot be represented using 4-bits in sign & magnitude form and 1's complement form. So we go for 8-bit representation. Similarly in 2's complement method, if we want to handle numbers outside the range -8 to +7, eight bits are required.

In 8-bits implementation, the numbers from -128 to +127 can be represented in 2's complement method. The range will be -127 to +127 for the other two methods. For the numbers outside this range, we use 16 bits and so on for all the representations.

Add it with larger number, i.e.

$$\begin{array}{r}
 1010 \quad + \\
 \underline{1011} \\
 1\ 0101 \\
 0101 \quad + \\
 \underline{1} \\
 0110
 \end{array}$$

MSB

The result is

MSB is removed and added with the result

Subtraction using 2's complement

To subtract a smaller binary number from a larger binary number the following are the steps.

- Step 1:** Add 0s to the left of smaller number, if necessary, to make the two numbers have the same number of bits.
- Step 2:** Find 2's complement of subtrahend (Number to be subtracted, here the smaller number).
- Step 3:** Add the 2's complement with minuend (Number from which subtracting, here the larger number).
- Step 3:** Ignore the carry.

Example: Subtract $(100)_2$ from $(1010)_2$ using 2's complement.

$$\begin{array}{r}
 \text{2's complement of } 0100 \quad 1100 \\
 \text{Add it with larger number, i.e.} \quad 1010 \quad + \\
 \underline{1100} \\
 1\ 0110
 \end{array}$$

Ignore the carry to get the result

The result is

b. Representation of floating point numbers

A floating point number / real number consists of an integer part and a fractional part. A real number can be written in a special notation called the floating point notation. Any number in this notation contains two parts, ***mantissa*** and ***exponent***.

For example, 25.45 can be written as 0.2545×10^2 , where 0.2545 is the mantissa and the power 2 is the exponent. (In normalised floating point notation mantissa is between 0.1 and 1). Similarly -0.0035 can be written as -0.35×10^{-2} , where -0.35 is mantissa and -2 is exponent.

Let us see how a real number is represented in 32 bit word length computer. Here 24 bits are used for storing mantissa (among these the first bit is for sign) and 8 bits are used for storing exponent (first bit for sign) as in Figure 2.3. Assume that decimal

point is to the right of the sign bit of mantissa. No separate space is reserved for storing decimal point.

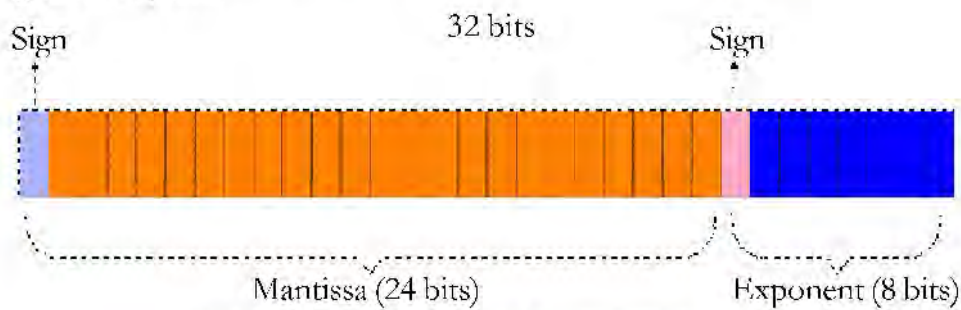


Fig 2.3: Representation of floating point numbers

Consider the real number 25.45 mentioned earlier, that can be written as 0.2545×10^2 , where 0.2545 is the mantissa and 2 is the exponent. These numbers are converted into binary and stored in respective locations. Various standards are followed for representing mantissa and exponent. When word length changes, bits used for storing mantissa and exponents will change accordingly.



In real numbers, binary point keeps track of mantissa part and exponent part. Since the value of mantissa and exponent varies from number to number the binary point is not fixed. In other words it floats and hence such a representation is called floating point representation.

2.4.2 Representation of characters

We have discussed methods for representing numbers in computer memory. Similarly there are different methods to represent characters. Some of them are discussed below.

a. ASCII

The code called ASCII (pronounced “AS-key”), which stands for American Standard Code for Information Interchange, uses 7 bits to represent each character in computer memory. The ASCII representation has been adopted as a standard by the U.S. government and is widely accepted. A unique integer number is assigned to each character. This number called ASCII code of that character is converted into binary for storing in memory. For example, ASCII code of A is 65, its binary equivalent in 7-bit is 1000001. Since there are exactly 128 unique combinations of 7 bits, this 7-bit code can represent only 128 characters.

Another version is ASCII-8, also called extended ASCII, which uses 8 bits for each character, can represent 256 different characters. For example, the letter A is represented by 01000001, B by 01000010 and so on. ASCII code is enough to represent all of the standard keyboard characters.

b. EBCDIC

It stands for Extended Binary Coded Decimal Interchange Code. This is similar to ASCII and is an 8 bit code used in computers manufactured by International Business Machine (IBM). It is capable of encoding 256 characters. If ASCII coded data is to be used in a computer which uses EBCDIC representation, it is necessary to transform ASCII code to EBCDIC code. Similarly if EBCDIC coded data is to be used in a ASCII computer, EBCDIC code has to be transformed to ASCII.

c. ISCII

ISCII stands for Indian Standard Code for Information Interchange or Indian Script Code for Information Interchange. It is an encoding scheme for representing various writing systems of India. ISCII uses 8-bits for data representation. It was evolved by a standardisation committee under the Department of Electronics during 1986-88, and adopted by the Bureau of Indian Standards (BIS). Nowadays ISCII has been replaced by Unicode.

d. Unicode

Using 8-bit ASCII we can represent only 256 characters. This cannot represent all characters of written languages of the world and other symbols. Unicode is developed to resolve this problem. It aims to provide a standard character encoding scheme, which is universal and efficient. It provides a unique number for every character, no matter what the language and platform be.

Unicode originally used 16 bits which can represent up to 65,536 characters. It is maintained by a non-profit organisation called the Unicode Consortium. The Consortium first published the version 1.0.0 in 1991 and continues to develop standards based on that original work. Nowadays Unicode uses more than 16 bits and hence it can represent more characters. Unicode can represent characters in almost all written languages of the world.

2.4.3 Representation of audio, image and video

In the previous sections we have discussed different data representation techniques and standards used for the computer representation of numbers and characters. While we attempt to solve real life problems with the aid of a digital computer, in most cases we may have to represent and process data other than numbers and characters. This may include audio data, images and videos. We can see that like numbers and characters, the audio, image and video data also carry information. In this section we will see different file formats for storing sound, image and video.

Digital audio, image and video file formats

Multimedia data such as audio, image and video are stored in different types of files. The variety of file formats is due to the fact that there are quite a few approaches to compressing the data and a number of different ways of packaging the data. For example an image is most popularly stored in Joint Picture Experts Group (JPEG) file format. An image file consists of two parts - header information and image data. Information such as name of the file, size, modified data, file format, etc. are stored in the header part. The intensity value of all pixels is stored in the data part of the file.

The data can be stored uncompressed or compressed to reduce the file size. Normally, the image data is stored in compressed form. Let us understand what compression is. Take a simple example of a pure black image of size 400×400 pixels. We can repeat the information black, black, ..., black in all 16,0000 (400×400) pixels. This is the uncompressed form, while in the compressed form black is stored only once and information to repeat it 1,60,000 times is also stored. Numerous such techniques are used to achieve compression. Depending on the application, images are stored in various file formats such as bitmap file format (BMP), Tagged Image File Format (TIFF), Graphics Interchange Format (GIF), Portable (Public) Network Graphic (PNG).

What we said about the header file information and compression is also applicable for audio and video files. Digital audio data can be stored in different file formats like WAV, MP3, MIDI, AIFF, etc. An audio file describes a format, sometimes referred to as the 'container format', for storing digital audio data. For example WAV file format typically contains uncompressed sound and MP3 files typically contain compressed audio data. The synthesised music data is stored in MIDI (Musical Instrument Digital Interface) files. Similarly video is also stored in different files such as AVI (Audio Video Interleave) - a file format designed to store both audio and video data in a standard package that allows synchronous audio with video playback, MP3, JPEG-2, WMV, etc.

Check yourself



1. Which is the MSB of representation of -80 in the sign and magnitude method?
2. Write 28.756 in mantissa exponent form.
3. ASCII stands for _____.
4. Represent -60 in 1's complement form.
5. Define Unicode.
6. List any two image file formats.

2.5 Introduction to Boolean algebra

In many situations in our life we face questions that require 'Yes' or 'No' answers. Similarly much of our thinking process involves answering questions with 'Yes' or 'No'. The way of finding truth by answering such two-valued questions is known as human reasoning or logical reasoning. These values can be expressed as 'True' or 'False' and numerically 1 or 0. These values are known as binary values or Boolean values. Boolean algebra is the algebra of logic which is a part of mathematical algebra that deals with the operations on variables that represent the values 1 and 0. The name Boolean algebra is given to honour the British mathematician George Boole, as he was the person who established the link between logic and mathematics. His revolutionary paper 'An Investigation of the laws of thought' led to the development of Boolean algebra.



Fig. 2.4: George Boole (1815 - 1864)

2.5.1 Binary valued quantities

Let us consider the following:

1. Should I take an umbrella?
2. Will you give me your pen?
3. George Boole was a British mathematician.
4. Kerala is the biggest state in India.
5. Why were you absent yesterday?
6. What is your opinion about Boolean algebra?

1st and 2nd sentences are questions which can be answered as YES or NO. These cases are called binary decisions and the results are called binary values. The 3rd statement is TRUE and 4th statement is FALSE. But 5th and 6th sentences cannot be answered like the cases above. The sentences which can be determined to be TRUE or FALSE are called **logical statements** or truth functions and the results TRUE or FALSE are called binary values or logical constants. The **logical constants** are represented by 1 and 0, where 1 stands for TRUE and 0 for FALSE. The variables which can store (hold) logical constants 1 and 0 are called logical variables or **Boolean variables**.

2.5.2 Boolean operators and logic gates

We have already seen that data fed to a computer must be converted into a combination of 1s and 0s. All data, information and operations are represented inside the computer

using 0s and 1s. The operations performed on these Boolean values are called **Boolean operations**. As we know, operators are required to perform these operations. These operators are called Boolean operators or logical operators. There are three basic logical operators in Boolean algebra. These operators and their operations are as follows:

- OR → Logical Addition
- AND → Logical Multiplication
- NOT → Logical Negation

The first two operators require two operands and the third requires only one operand. Here the operands are always Boolean variable or constants and the result will always be either True (1) or False (0).

Computers perform these operations with some electronic circuits, called logic circuits. A logic circuit is made up of individual units called gates, where a gate represents a Boolean operation. A **Logic gate** is a physical device that can perform logical operations on one or more logical inputs and produce a single logical output. Logic gates are primarily implemented using diodes or transistors acting as electronic switches. There are three basic logic gates and they represent the three basic Boolean operations. These gates are OR, AND and NOT.

a. The OR operator and OR gate

Let us consider a real life situation. When do you use an umbrella? When it rains, isn't it? And of course, if it is too sunny. We can combine these two situations using a compound statement like "If it is raining or if it is sunny, we use an umbrella". Note down the use of **or** in this statement. The interpretation of this statement can be shown as in Table 2.8. The logical reasoning of the use of umbrella in our example very much resembles the Boolean OR operation.

Raining	Sunny	Need Umbrella
No	No	No
No	Yes	Yes
Yes	No	Yes
Yes	Yes	Yes

Table 2.8: Logical OR operation

The OR operator performs logical addition and the symbol used for this operation is + (plus). The expression $A + B$ is read as A OR B. Table 2.9 is the truth table that represents the OR operation. Assume that the variables A and B are the inputs (operands) and $A + B$ is the output (result). It is clear from the truth table that, if any one of the inputs is 1 (True), the output will be 1 (True).

Truth Table is a table that shows Boolean operations and their results. It lists all possible inputs for the given operation and their corresponding output. Usually these operations consist of operand variables and operators. The operands and the operators together are called Boolean expression. Truth

Table represents all possible values of the operands and the corresponding results (values) of the operation. A Boolean expression with m operands (variables) and n operators require 2^m rows and $m + n$ columns.

While designing logic circuits, the logic gate used to implement logical OR operation is called logical **OR gate**. Figure 2.5 shows the OR gate symbol in Boolean algebra.



Fig. 2.5 : Logical OR gate

The working of this gate can be illustrated with an electronic circuit. Figure 2.6 illustrates the schematic circuit of parallel switches which shows the idea of an OR gate. Here A and B are two switches and Y is a bulb. Each switch and the bulb can take either close (ON) or open (OFF) state. Now let us relate the operation of the above circuit with the functioning of OR gate. Assume that 'OFF' represents the logical LOW state (say 0) and ON represents the logical HIGH (say 1) state. If we consider the state of switches A and B as input to the OR gate and state of bulb as output of OR gate, then the truth table shown in Table 2.9 will describe the operation of an OR gate. Thus the Boolean expression for OR gate can be written as: $Y = A + B$

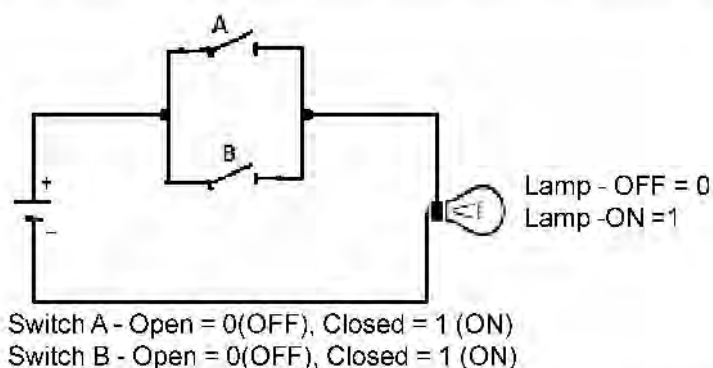


Fig. 2.6 : Circuit with two switches and a bulb for parallel connection

An OR gate can take more than two inputs. Let us see what will be the truth table, Boolean expression and logical symbol for the three input OR gate.

The truth table and the gate symbol shows that, the Boolean expression for the OR gate with three inputs is $Y = A + B + C$. Figure 2.7 shows the representation of OR gate with three inputs. From the truth tables 2.9 and 2.10, we can see that the output of OR gate is 1 if any input is 1; and output is 0 if and only if all inputs are 0.



Fig 2.7 : OR gate
with three inputs

A	B	C	$A + B + C$
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

Table 2.10 : Truth table for OR gate with 3 inputs

b. The AND operator and AND gate

We will discuss another situation to understand the concept of AND Boolean operation. Suppose you are away from home and it is lunch time. You can have your food only if two conditions are satisfied – (i) there should be a hotel and (ii) you should have enough money. Here also, we can make a compound statement like “If there is a hotel and if we have money, we can have food”. Note the use of **and** in this statement. Table 2.11 shows the logical reasoning of getting food and it very much resembles the Boolean AND operation.

Hotel	Money	Take Food
No	No	No
No	Yes	No
Yes	No	No
Yes	Yes	Yes

Table 2.11 : Logical AND operation

A	B	$A \cdot B$
0	0	0
0	1	0
1	0	0
1	1	1

Table 2.12 : Truth table of AND operation

The AND operator performs logical multiplication and the symbol used for this operation is \cdot (dot). The expression $A \cdot B$ is read as A AND B. Table 2.12 is the truth table that represents the AND operation. Assume that the variables A and B are the inputs (operands) and $A \cdot B$ is the output (result).

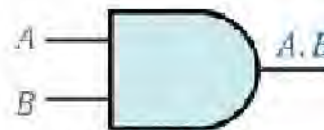


Fig. 2.8 : Logical AND gate

While designing logic circuits, the logic gate used to implement logical AND operation is called logical **AND gate**. Figure 2.8 shows the AND gate symbol in Boolean algebra.

The working of this gate can be illustrated with an electronic circuit shown in Figure 2.9. This schematic circuit has two serial switches which illustrates the idea of an AND gate. Here A and B are two switches and Y is a bulb. Each switch and the bulb can take either close (ON) or open (OFF) state. Now let us relate the operation of the above circuit with

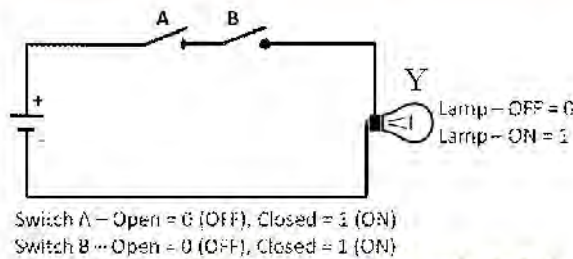


Fig. 2.9 : Circuit with two switches and a bulb for serial connection

the functioning of AND gate. Assume that OFF represents the logical LOW state (say 0) and ON represents the logical HIGH state (say 1). If we consider the state of switches A and B as input to the AND gate and state of bulb as output of AND gate, then the Boolean expression for AND gate can be written as: $Y = A \cdot B$

An AND gate can take more than two inputs. Let us see what will be the truth table, Boolean expression and logical symbol for three input AND gate. The truth table and the gate symbol shows that the Boolean expression for the AND gate with three inputs is $Y = A \cdot B \cdot C$

Figure 2.10 shows the representation of AND gate with three inputs. From Truth Tables 2.12 and 2.13, we can see that the output of AND gate is 0 if any input is 0; and output is 1 if and only if all inputs are 1.

A	B	C	A.B.C
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

Table 2.13 : Truth table for AND gate with 3 inputs



Fig. 2.10 : AND gate with three inputs.

c. The NOT operator and NOT gate

Let us discuss another case to familiarise the Boolean NOT operation. Suppose you jog everyday in the morning. Can you do it every day? If it rains, can you jog in the morning? Table 2.14 shows all the possibilities of this situation. It is quite similar to Boolean NOT operation.

It is a unary operator and hence it requires only one operand. The NOT operator performs logical negation and the symbol used for this operation is - (over-bar).

Raining	Jogging
No	Yes
Yes	No

Table 2.14: Logical NOT

The expression \bar{A} is read as A bar. It is also expressed as A' and read as A dash. Table 2.15 is the truth table that represents the NOT operation. Assume that the variable A is the input (operand) and \bar{A} is the output (result). It is clear from the truth table that, the output will be the opposite value of the input. The logic gate used to implement NOT operation is NOT gate. Figure 2.11 shows the NOT gate symbol.

A	\bar{A}
0	1
1	0

Table 2.15 : Truth table of NOT operation

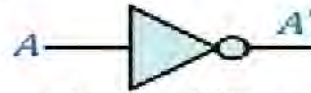


Fig. 2.11 : NOT gate

A NOT gate is also called **inverter**. It has only one input and one output. The input is always changed into its opposite state. If input is 0, the NOT gate will give its complement or opposite which is 1. If the input is 1, then the NOT gate will complement it to 0.

Check yourself



1. Define the term Boolean variable.
2. A logic circuit is made up of individual units called _____.
3. Name the logical operator/gate which gives high output if and only if all the inputs are high.
4. Define the term truth table.
5. An AND operation performs logical _____ and an OR operation performs logical _____.
6. Draw the logic symbol of OR gate.

2.6 Basic postulates of Boolean algebra

Boolean algebra being a system of mathematics, consists of certain fundamental laws. These fundamental laws are called postulates. They do not have proof, but are made to build solid framework for scientific principles. On the other hand, there are some theorems in Boolean algebra which can be proved based on these postulates and laws.

Postulate 1: Principles of 0 and 1

If $A \neq 0$, then $A = 1$ and if $A \neq 1$, then $A = 0$

Postulate 2: OR Operation (Logical Addition)

$$0 + 0 = 0 \quad 0 + 1 = 1 \quad 1 + 0 = 1 \quad 1 + 1 = 1$$

Postulate 3: AND Operation (Logical Multiplication)

$$0 \cdot 0 = 0 \quad 0 \cdot 1 = 0 \quad 1 \cdot 0 = 0 \quad 1 \cdot 1 = 1$$

Postulate 4: NOT Operation (Logical Negation or Compliment Rule)

$$\bar{0} = 1 \quad \bar{1} = 0$$

Principle of Duality

When Boolean variables and/or values are combined with Boolean operators, Boolean expressions are formed. $X + Y$ and $\bar{A} + 1$ are examples of Boolean expressions. The postulates 2, 3 and 4 are all Boolean statements. Consider the statements in postulate 2. If we change the value 0 by 1 and 1 by 0, and the operator OR (+) by AND (.), we will get the statements in postulate 3. Similarly, if we change the value 0 by 1 and 1 by 0, and the operator AND (.) by OR (+) in statements of postulate 3, we will get the statements of postulate 2. This concept is known as principle of duality.

The principle of duality states that for a Boolean statement, there exists its dual form, which can be derived by

- (i) changing each OR sign (+) to AND sign (.)
- (ii) changing each AND sign (.) to OR sign (+)
- (iii) replacing each 0 by 1 and each 1 by 0

2.7 Basic theorems of Boolean algebra

There are some standard and accepted rules in every theory. The set of rules are known as **axioms** of the theory. A conclusion can be derived from a set of presumptions by using these axioms or postulates. This conclusion is called law or theorem. Theorems of Boolean algebra provide tools for simplification and manipulation of Boolean expressions. Let us discuss some of these laws or theorems. These laws or theorems can be proved using truth tables and Boolean laws that are already proved.

2.7.1 Identity law

If X is a Boolean variable, the law states that:

- (i) $0 + X = X$
- (ii) $1 + X = 1$
- (iii) $0 \cdot X = 0$
- (iv) $1 \cdot X = X$

Statements (i) and (ii) are known as additive identity law; and statements (iii) and (iv) are called multiplicative identity. Also note that, statement (iv) is the dual of (i) and vice versa. Similarly, statements (ii) and (iii) are dual forms. The truth tables shown in Tables 2.16(a), 2.16(b), 2.17(a) and 2.17 (b) prove these laws.

0	X	0 + X
0	0	0
0	1	1

Table 2.16 (a) : Additive Identity law

1	X	1 + X
1	0	1
1	1	1

Table 2.16 (b) : Additive Identity law

Table 2.16 (a) shows that columns 2 and 3 are the same and it is proved that $0 + X = X$. Similarly, columns 1 and 3 of table 2.16 (b) are the same and hence the statement $1 + X = 1$ is true.

0	X	0 . X
0	0	0
0	1	0

Table 2.17(a) : Multiplicative Identity law

1	X	1 . X
1	0	0
1	1	1

Table 2.17(b) : Multiplicative Identity law

Table 2.17 (a) shows that columns 1 and 3 are the same and it is proved that $0 . X = 0$. Similarly, columns 2 and 3 of Table 2.17 (b) are the same and hence the statement $1 . X = X$ is true.

2.7.2 Idempotent law

The idempotent law states that: (i) $X + X = X$
and (ii) $X . X = X$

If the value of X is 0, the statements are true, because $0 + 0 = 0$ (Postulate 2) and $0 . 0 = 0$ (Postulate 3). Similarly the statements will be true

X	X	X + X	X	X	X . X
0	0	0	0	0	0
1	1	1	1	1	1

Table 2.18 (a) : Idempotent law

Table 2.18 (b) : Idempotent law

when the value of X is 1. Truth Tables 2.18 (a) and 2.18 (b) shows the proof of these laws. Also note that the statements are dual to each other.

2.7.3 Involution law

This law states that: $\overline{\overline{X}} = X$

Let $X = 0$, then $\overline{X} = 1$ (Postulate 4); and if we take its complement, $\overline{\overline{X}} = \overline{1} = 0$, which is same as X. The statement will also be true, when the value of X is 1.

Columns 1 and 3 of Table 2.19 show that $\overline{\overline{X}} = X$.

X	\overline{X}	$\overline{\overline{X}}$
0	1	0
1	0	1

Table 2.19 : Involution law

2.7.4 Complimentary law

The complimentary law states that: (i) $X + \bar{X} = 1$

and (ii) $X \cdot \bar{X} = 0$

If the value of X is 0, then \bar{X} becomes 1. Hence, $X + \bar{X}$ becomes $0 + 1$, which results into 1 (*Postulate 2*). Similarly when X is 1, \bar{X} will be 0. The truth tables 2.20 (a) and 2.20 (b) show the proof of these laws taking all the possibilities. Also note that the statements are dual to each other.

X	\bar{X}	$X + \bar{X}$	X	\bar{X}	$X \cdot \bar{X}$
0	1	1	0	1	0
1	0	1	1	0	0

Table 2.20 (a) : Complimentary law

Table 2.20 (b) : Complimentary law

2.7.5 Commutative law

Commutative law allows to change the position of variables in OR and AND operations. If X and Y are two variables, the law states that:

(i) $X + Y = Y + X$

and (ii) $X \cdot Y = Y \cdot X$

The truth table shown in Tables 2.21 (a) and 2.21 (b) prove these statements.

X	Y	$X + Y$	$Y + X$	X	Y	$X \cdot Y$	$Y \cdot X$
0	0	0	0	0	0	0	0
0	1	1	1	0	1	0	0
1	0	1	1	1	0	0	0
1	1	1	1	1	1	1	1

Table 2.21 (a) : Commutative law

Table 2.21 (b) : Commutative law

The law ensures that order of the operands for OR and AND operations does not affect the output in each case.

2.7.6 Associative law

In the case of three operands for OR and AND operations, associative law allows grouping of operands differently. If X , Y and Z are three variables, the law states that:

(i) $X + (Y + Z) = (X + Y) + Z$

and (ii) $X \cdot (Y \cdot Z) = (X \cdot Y) \cdot Z$

The truth tables shown in Tables 2.22(a) and 2.22(b) prove these statements.

X	Y	Z	$X + Y$	$Y + X$	$X + (Y + Z)$	$(X + Y) + Z$
0	0	0	0	0	0	0
0	0	1	0	1	1	1
0	1	0	1	1	1	1
0	1	1	1	1	1	1
1	0	0	1	0	1	1
1	0	1	1	1	1	1
1	1	0	1	1	1	1
1	1	1	1	1	1	1

Table 2.22(a) : Associative law 1

In Table 2.22(a), columns 6 and 7 show that $X + (Y + Z) = (X + Y) + Z$. Columns 6 and 7 of Table 2.22(b) show the validity of the experience $X \cdot (Y \cdot Z) = (X \cdot Y) \cdot Z$.

X	Y	Z	$X \cdot Y$	$Y \cdot Z$	$X \cdot (Y \cdot Z)$	$(X \cdot Y) \cdot Z$
0	0	0	0	0	0	0
0	0	1	0	0	0	0
0	1	0	0	0	0	0
0	1	1	0	1	0	0
1	0	0	0	0	0	0
1	0	1	0	0	0	0
1	1	0	1	0	0	0
1	1	1	1	1	1	1

Table 2.22(b) : Associative law 2

Associative law ensures that the order and combination of variables in OR (logical addition) or AND (logical multiplication) operations do not affect the final output.

2.7.7 Distributive law

Distributive law states that Boolean expression can be expanded by multiplying terms as in ordinary algebra. It also supports expansion of addition operation over multiplication. If X, Y and Z are variables, the law states that:

$$(i) X \cdot (Y + Z) = X \cdot Y + X \cdot Z$$

$$\text{and} \quad (ii) X + Y \cdot Z = (X + Y) \cdot (X + Z)$$

The following truth tables prove these statements:

X	Y	Z	$Y + Z$	$X.(Y+Z)$	$X.Y$	$X.Z$	$X.Y + X.Z$
0	0	0	0	0	0	0	0
0	0	1	1	0	0	0	0
0	1	0	1	0	0	0	0
0	1	1	1	0	0	0	0
1	0	0	0	0	0	0	0
1	0	1	1	1	0	1	1
1	1	0	1	1	1	0	1
1	1	1	1	1	1	1	1

Table 2.23(a) : Distribution of Multiplication over Addition

Columns 5 and 8 of Table 2.23(a) show that $X.(Y + Z) = X.Y + X.Z$

X	Y	Z	$Y.Z$	$X + Y.Z$	$X+Y$	$X+Z$	$(X+Y).(X+Z)$
0	0	0	0	0	0	0	0
0	0	1	0	0	0	1	0
0	1	0	0	0	1	0	0
0	1	1	1	1	1	1	1
1	0	0	0	1	1	1	1
1	0	1	0	1	1	1	1
1	1	0	0	1	1	1	1
1	1	1	1	1	1	1	1

Table 2.23(b) : Distribution of Addition over Multiplication

Columns 5 and 8 of Table 2.23(b) show that $X + Y.Z = (X + Y).(X + Z)$

We are familiar with the first statement in ordinary algebra. To remember the second statement of this law, find the dual form of the first.

2.7.8 Absorption law

Absorption law is a kind of distributive law in which two variables are used and the result will be one of them. If X and Y are variables, the absorption law states that:

$$(i) X + (X.Y) = X$$

$$\text{and} \quad (ii) X.(X + Y) = X$$

The truth tables shown Tables 2.24(a) and 2.24(b) prove the validity of the statements of absorption law.

X	Y	$X \cdot Y$	$X + (X \cdot Y)$
0	0	0	0
0	1	0	0
1	0	0	1
1	1	1	1

Table 2.24 (a) : Absorption law

X	Y	$X + Y$	$X \cdot (X + Y)$
0	0	0	0
0	1	1	0
1	0	1	1
1	1	1	1

Table 2.24 (b) : Absorption law

Columns 1 and 4 of Table 2.24(a) and columns 1 and 4 of Table 2.24(b) show that the laws are true.

Table 2.25 depicts all the Boolean laws we have discussed so far.

No.	Boolean Law	Statement 1	Statement 2
1	Additive Identity	$0 + X = X$	$1 + X = 1$
2	Multiplicative Identity	$0 \cdot X = 0$	$1 \cdot X = X$
3	Idempotent Law	$X + X = X$	$X \cdot X = X$
4	Involution Law	$\overline{\overline{X}} = X$	
5	Complimentary Law	$X + \overline{X} = 1$	$X \cdot \overline{X} = 0$
6	Commutative Law	$X + Y = Y + X$	$X \cdot Y = Y \cdot X$
7	Associative Law	$X + (Y + Z) = (X + Y) + Z$	$X \cdot (Y \cdot Z) = (X \cdot Y) \cdot Z$
8	Distributive Law	$X \cdot (Y + Z) = X \cdot Y + X \cdot Z$	$X + (Y \cdot Z) = (X + Y) \cdot (X + Z)$
9	Absorption Law	$X + (X \cdot Y) = X$	$X \cdot (X + Y) = X$

Table 2.25 : Boolean laws

The laws we discussed have been proved using truth tables. Some of them can be proved by applying some other laws. This method of proof is called algebraic proof. Let us see some of them.

i. To prove that $X \cdot (X + Y) = X$ – Absorption law

$$\begin{aligned}
 \text{LHS} &= X \cdot (X + Y) \\
 &= X \cdot X + X \cdot Y && \text{(Distribution of multiplication over addition)} \\
 &= X + X \cdot Y && \text{(Idempotent law)} \\
 &= X \cdot (1 + Y) && \text{(Distribution of multiplication over addition)}
 \end{aligned}$$

$$\begin{aligned}
 &= X \cdot 1 && (\text{Additive identity}) \\
 &= X && (\text{Multiplicative identity}) \\
 &= \text{RHS}
 \end{aligned}$$

ii. To prove that $X + (X \cdot Y) = X$ – Absorption law

$$\begin{aligned}
 \text{LHS} &= X + (X \cdot Y) \\
 &= X \cdot 1 + X \cdot Y && (\text{Multiplicative identity}) \\
 &= X \cdot (1 + Y) && (\text{Distribution of multiplication over addition}) \\
 &= X \cdot 1 && (\text{Additive identity}) \\
 &= X && (\text{Multiplicative identity}) \\
 &= \text{RHS}
 \end{aligned}$$

iii. To prove that $X + (Y \cdot Z) = (X+Y) \cdot (X+Z)$ – Distributive Law

Let us take the expression on the RHS of this statement.

$$\begin{aligned}
 &(X+Y) \cdot (X+Z) \\
 &= (X+Y) \cdot X + (X+Y) \cdot Z && (\text{Distribution of multiplication over addition}) \\
 &= X \cdot (X+Y) + Z \cdot (X+Y) && (\text{Commutative law}) \\
 &= X \cdot X + X \cdot Y + Z \cdot X + Z \cdot Y && (\text{Distribution of multiplication over addition}) \\
 &= X + X \cdot Y + Z \cdot X + Z \cdot Y && (\text{Idempotent law}) \\
 &= X \cdot 1 + X \cdot Y + Z \cdot X + Z \cdot Y && (\text{Multiplicative identity}) \\
 &= X \cdot (1 + Y) + Z \cdot X + Z \cdot Y && (\text{Distribution of multiplication over addition}) \\
 &= X \cdot 1 + Z \cdot X + Z \cdot Y && (\text{Additive identity}) \\
 &= X \cdot (1 + Z) + Z \cdot Y && (\text{Distribution of multiplication over addition}) \\
 &= X \cdot 1 + Z \cdot Y && (\text{Additive identity}) \\
 &= X + Y \cdot Z && (\text{Multiplicative identity and Commutative law}) \\
 &= \text{LHS}
 \end{aligned}$$

The expression obtained is the LHS of the given statement. Thus the theorem is proved.

2.8 De Morgan's theorems

Augustus De Morgan (1806 – 1871), a famous logician and mathematician of University College, London proposed two theorems to simplify complicated Boolean expressions. These theorems are known as De Morgan's theorems. The two theorems are:

$$(i) \quad \overline{X+Y} = \overline{X} \cdot \overline{Y}$$

$$(ii) \quad \overline{X \cdot Y} = \overline{X} + \overline{Y}$$

Literally these theorems can be stated as

- (i) “the complement of sum of Boolean variables is equal to product of their individual complements” and
- (ii) “the complement of product of Boolean variables is equal to sum of their individual complements”.

Algebraic proof of the first theorem

We have to prove that, $\overline{X+Y} = \overline{X} \cdot \overline{Y}$

Let us assume that, $Z = X + Y$ _____ (1)

Then, $\overline{Z} = \overline{X+Y}$ _____ (2)

We know that, by complimentary law, the equations (3) and (4) are true.

$$Z + \overline{Z} = 1 \quad \text{_____ (3)}$$

$$Z \cdot \overline{Z} = 0 \quad \text{_____ (4)}$$

Substituting expressions (1) in (3) and (2) in (4), we will get equations (5) and (6).

$$(X + Y) + (\overline{X+Y}) = 1 \quad \text{_____ (5)}$$

$$(X + Y) \cdot (\overline{X+Y}) = 0 \quad \text{_____ (6)}$$

For the time being let us assume that De Morgan's first theorem is true. If so, $(\overline{X+Y})$ in equations (5) and (6) can be substituted with $(\overline{X} \cdot \overline{Y})$. Thus equations (5) and (6) can be modified as follows:

$$(X+Y) + (\overline{X} \cdot \overline{Y}) = 1 \quad \text{_____ (7)}$$

$$(X+Y) \cdot (\overline{X} \cdot \overline{Y}) = 0 \quad \text{_____ (8)}$$

Now we will prove equations (7) and (8) separately. If they are correct, we can conclude that the assumptions we made to form those equations are also correct. That is, if equations (7) and (8) are true, De Morgan's theorem is also true.

Consider the LHS of equation (7),

$$\begin{aligned} (X+Y) + (\overline{X} \cdot \overline{Y}) &= (X+Y+\overline{X}) \cdot (X+Y+\overline{Y}) && \text{(Distributive Law)} \\ &= (X+\overline{X}+Y) \cdot (X+Y+\overline{Y}) && \text{(Associative Law)} \\ &= (1+Y) \cdot (X+1) && \text{(Complimentary Law)} \end{aligned}$$

$$\begin{aligned}
 &= 1 \cdot 1 && (\text{Additive Identity}) \\
 &= 1 \\
 &= \text{RHS}
 \end{aligned}$$

Now, let us consider the LHS of equation (8),

$$\begin{aligned}
 (X + Y) \cdot (\overline{X} \cdot \overline{Y}) &= (X \cdot \overline{X} \cdot \overline{Y}) + (Y \cdot \overline{X} \cdot \overline{Y}) && (\text{Distributive Law}) \\
 &= (X \cdot \overline{X} \cdot \overline{Y}) + (Y \cdot \overline{Y} \cdot \overline{X}) && (\text{Associative Law}) \\
 &= (0 \cdot \overline{Y}) + (0 \cdot \overline{X}) && (\text{Complimentary Law}) \\
 &= 0 + 0 && (\text{Multiplicative Identity}) \\
 &= 0 \\
 &= \text{RHS}
 \end{aligned}$$

We have algebraically proved equations (7) and (8), which mean that De Morgan's first theorem is proved. The theorem can also be proved using truth table, but it is left to you as an exercise.

Algebraic proof of the second theorem

We have to prove that, $\overline{X \cdot Y} = \overline{X} + \overline{Y}$

Let us assume that, $Z = X \cdot Y$ _____ (1)

Then, $\overline{Z} = \overline{X \cdot Y}$ _____ (2)

We know that, by complimentary laws the equations (3) and (4) are true.

$$Z + \overline{Z} = 1 \quad \text{_____ (3)}$$

$$Z \cdot \overline{Z} = 0 \quad \text{_____ (4)}$$

Substituting expressions (1) in (3) and (2) in (4), we will get the expressions (5) and (6).

$$(X \cdot Y) + (\overline{X \cdot Y}) = 1 \quad \text{_____ (5)}$$

$$(X \cdot Y) \cdot (\overline{X \cdot Y}) = 0 \quad \text{_____ (6)}$$

For the time being let us assume that De Morgan's second theorem is true. If so, $(\overline{X \cdot Y})$ in equations 5 and 6 can be substituted with $(\overline{X} + \overline{Y})$. Thus equations (5) and (6) can be modified as follows:

$$(X \cdot Y) + (\overline{X} + \overline{Y}) = 1 \quad \text{_____ (7)}$$

$$(X \cdot Y) \cdot (\overline{X} + \overline{Y}) = 0 \quad \text{_____ (8)}$$

Now we will prove equations (7) and (8) separately. If they are correct, we can conclude that the assumptions we made to form those equations are also correct. That is, if equations (7) and (8) are true, De Morgan's theorem is also true.

Consider the LHS of equation (7),

$$\begin{aligned}
 (X \cdot Y) + (\bar{X} + \bar{Y}) &= (\bar{X} + \bar{Y}) + (X \cdot Y) && \text{(Commutative Law)} \\
 &= (\bar{X} + \bar{Y} + X) \cdot (\bar{X} + \bar{Y} + Y) && \text{(Distributive Law)} \\
 &= (\bar{X} + X + \bar{Y}) \cdot (\bar{X} + \bar{Y} + Y) && \text{(Associative Law)} \\
 &= (1 + \bar{Y}) \cdot (\bar{X} + 1) && \text{(Complimentary Law)} \\
 &= 1 \cdot 1 && \text{(Additive Identity)} \\
 &= 1 \\
 &= \text{RHS}
 \end{aligned}$$

Now, let us consider the LHS of equation (8),

$$\begin{aligned}
 (X \cdot Y) \cdot (\bar{X} + \bar{Y}) &= (X \cdot Y \cdot \bar{X}) + (X \cdot Y \cdot \bar{Y}) && \text{(Distributive Law)} \\
 &= (X \cdot \bar{X} \cdot Y) + (X \cdot Y \cdot \bar{Y}) && \text{(Associative Law)} \\
 &= (0 \cdot Y) + (X \cdot 0) && \text{(Complimentary Law)} \\
 &= 0 + 0 && \text{(Multiplicative Identity)} \\
 &= 0 \\
 &= \text{RHS}
 \end{aligned}$$

We have algebraically proved equations (7) and (8), which mean that De Morgan's second theorem is proved. The theorem can also be proved using truth table, but it is left to you as an exercise.



We can extend Demorgan's theorem for any number of variables as shown below:

$$\begin{aligned}
 \overline{A+B+C+D+\dots} &= \bar{A} \cdot \bar{B} \cdot \bar{C} \cdot \bar{D} \cdot \dots \\
 \overline{A \cdot B \cdot C \cdot D \cdot \dots} &= \bar{A} + \bar{B} + \bar{C} + \bar{D} + \dots
 \end{aligned}$$

Although the identities above represent De Morgan's theorem, the transformation is more easily performed by following the steps given below:

- (i) Complement the entire function
- (ii) Change all the ANDs (.) to ORs (+) and all the ORs (+) to ANDs (.)
- (iii) Complement each of the individual variables.

This process is called *demorganisation* and simply demorganisation is 'Break the line, change the sign'.

Check yourself



1. Find the dual of Boolean expression $A.B+B.C=1$
2. Name the law which states that $A+A=A$.
(a) Commutative law (b) Idempotent Law (c) Absorption Law
3. State De Morgan's theorems.

2.9 Circuit designing for simple Boolean expressions

By using basic gates, circuit diagrams can be designed for Boolean expressions. We have seen that the Boolean expressions $A.B$ is represented using an AND gate, $A+B$ is represented using an OR gate and \bar{A} is represented using a NOT gate. Let us see how a circuit is designed for other Boolean expressions.

Consider a boolean expression $\bar{A} + B$, which is an OR operation with two input and first input is inverted. So circuit diagram can be drawn as shown in Figure 2.12.

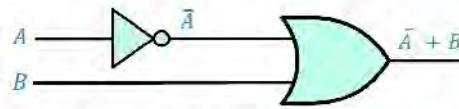


Fig 2.12 : $f(A, B) = \bar{A} + B$

Example: Construct a logical circuit for Boolean expression $f(X, Y) = X.Y + \bar{Y}$

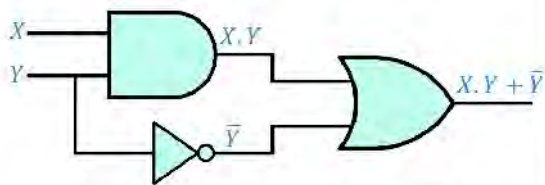


Fig 2.13 : $f(X, Y) = X.Y + \bar{Y}$

Example: Construct a logical expression for $f(a, b) = (a + b) . (\bar{a} + \bar{b})$

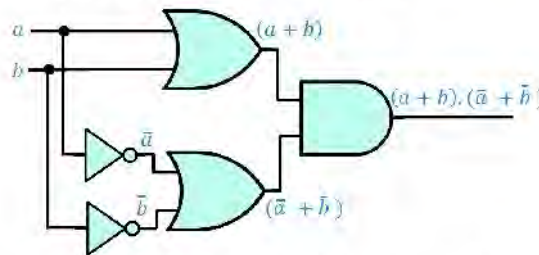


Fig 2.14 : $f(a, b) = (a + b) . (\bar{a} + \bar{b})$

Example: Construct logical circuit for the Boolean expression $\bar{a} . b + a . \bar{b}$

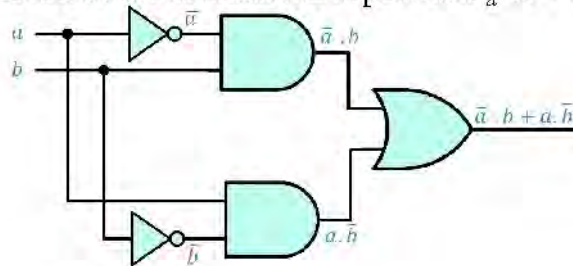


Fig 2.15 : $f(a, b) = \bar{a} . b + a . \bar{b}$

2.10 Universal gates

The NAND and NOR gates are called universal gates. A universal gate is a gate which can implement any Boolean function without using any other gate type. In practice, this is advantageous, since NAND and NOR gates are economical and easier to fabricate and are the basic gates used in most of IC digital logic families.

2.10.1 NAND gate

This is an AND gate with its output inverted by a NOT gate. The logical circuit arrangement is shown in Figure 2.16.

Note that A and B are the inputs of AND gate and its output is $(A.B)$. The output of AND gate is inverted by an inverter (NOT gate) to get the resultant output Y as $\overline{(A.B)}$. So the logical expression for a NAND gate is $\overline{(A.B)}$. From the truth table shown as Table 2.26, we can see that output of a NAND gate is 1 if any one of the input is 0. It produces output 0 if and only if all inputs are 1. This is the inverse operation of an AND gate. So we can say that **a NAND gate is an inverted AND gate.**



Fig. 2.16 : Circuit realisation of NAND gate

A	B	$Y = \overline{(A.B)}$
0	0	1
0	1	1
1	0	1
1	1	0

Table 2.26 : NAND truth table

The logical symbol of NAND gate is shown in Figure 2.17. Note that the NAND symbol is an AND symbol with a small bubble at the output. The bubble is sometimes called an invert bubble.

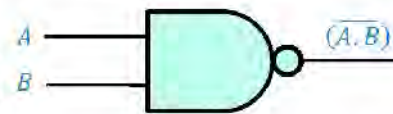


Fig. 2.17 : NAND gate

2.10.2 NOR gate

This is an OR gate with its output inverted by a NOT gate. The logical circuit arrangement is shown in Figure 2.18.

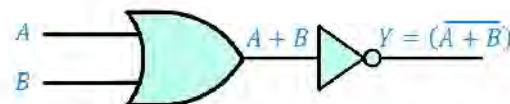


Fig. 2.18 : Circuit realisation of NOR gate

Note that A and B are the input of OR gate and its output is $(A+B)$. The output of OR gate is inverted by an inverter (NOT gate) to get resultant output as $\overline{(A+B)}$. So the logical expression for a NOR gate is $\overline{(A+B)}$. Let us see the truth table of the two input NOR gate.

From the truth table shown on as 'Table 2.27, we can see that output of a NOR gate is 1 if and only if all inputs are 0. If any one of the inputs is 1 it produces an output 0. This is the inverse operation of an OR gate. So we can say that **a NOR gate is an inverted OR gate.**

A	B	$Y = \overline{(A + B)}$
0	0	1
0	1	0
1	0	0
1	1	0

Table 2.27 : NOR truth table

The logical symbol of NOR gate is shown in Figure 2.19. Note that the NOR symbol is an OR symbol with a small bubble at the output.

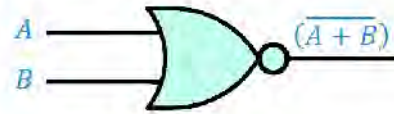


Fig. 2.19 : NOR gate

2.10.3 Implementation of basic gates using NAND and NOR

We can design all basic gates (AND, OR and NOT) using NAND or NOR gate alone. Let us see the implementation of basic gates using NAND gate.

NOT gate using NAND gate

We can implement a NOT gate (inverter) using a NAND by applying the same signal to both inputs of a NAND gate as shown in Figure 2.20.

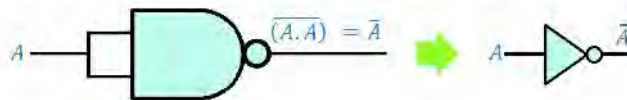


Fig. 2.20 : NOT gate using NAND gate

Proof:

$$A \text{ NAND } A = \overline{(A.A)}$$

$$= \bar{A} \quad \text{Since } A.A = A$$

The truth table shown as 'Table 2.28 is the proof for obtaining NOT gate using NAND gate.

A	AA	$\overline{(A.A)}$	\bar{A}
0	0	1	1
1	1	0	0

Table 2.28 : Proof using truth table

AND gate using NAND gate

We can implement an AND gate by using a NAND gate followed by another NAND gate to invert the output as shown in Figure 2.21.



Fig. 2.21 : AND gate using NAND gate

Proof

$$\begin{aligned}
 \text{We know that } A \text{ NAND } B &= (\overline{A \cdot B}) \\
 (A \text{ NAND } B) \text{ NAND } (A \text{ NAND } B) &= (\overline{A \cdot B}) \text{ NAND } (\overline{A \cdot B}) \\
 &= \overline{(\overline{A \cdot B}) \cdot (\overline{A \cdot B})} \\
 &= (\overline{\overline{A \cdot B}}) \quad \text{Since } A \cdot A = A \\
 &= A \cdot B \quad \text{Since } (\overline{\overline{A}}) = A
 \end{aligned}$$

Table 2.29 shows the proof for obtaining AND gate using NAND gate with the help of the truth table.

A	B	A.B	$\overline{(A.B)}$	$\overline{(A.B)} \cdot \overline{(A.B)}$	$\overline{(\overline{(A.B)} \cdot \overline{(A.B)})}$
0	0	0	1	1	0
0	1	0	1	1	0
1	0	0	1	1	0
1	1	1	0	0	1

Table 2.29 : Proof using truth table

OR gate using NAND gate

The OR gate is replaced by a NAND gate with all its inputs complemented by NAND gate inverters as shown in Figure 2.22.

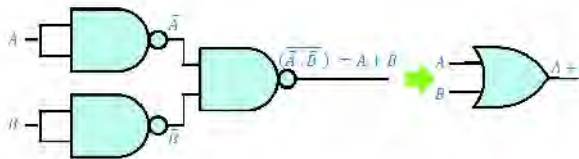
**Proof:**

Fig. 2.22 : OR gate using NAND gate

$$\begin{aligned}
 A \text{ NAND } A &= (\overline{A \cdot A}) \\
 &= \overline{A}
 \end{aligned}$$

$$\text{Similarly, } B \text{ NAND } B = \overline{B}$$

$$\begin{aligned}
 \text{Therefore, } (A \text{ NAND } A) \text{ NAND } (B \text{ NAND } B) &= \overline{A} \text{ NAND } \overline{B} \\
 &= \overline{(\overline{A} \cdot \overline{B})} \\
 &= \overline{\overline{A}} + \overline{\overline{B}} \quad \text{Since } (\overline{A \cdot B}) = \overline{A} + \overline{B} \\
 &= A + B \quad \text{Since } (\overline{\overline{A}}) = A
 \end{aligned}$$

Table 2.30 shows the proof for obtaining OR gate using NAND gate with the help of truth table.

A	B	\bar{A}	\bar{B}	$\bar{A} \cdot \bar{B}$	$\overline{(\bar{A} \cdot \bar{B})}$	$A + B$
0	0	1	1	1	0	0
0	1	1	0	0	1	1
1	0	0	1	0	1	1
1	1	0	0	0	1	1

Table 2.30 : Proof using truth table

Thus, the NAND gate is a universal gate since it can implement AND, OR and NOT operations. Now let us see implementation of basic gates by using another universal gate, the NOR gate.

NOT gate using NOR gate

We can implement a NOT gate (inverter) using a NOR by applying the same signal to both inputs of a NOR gate as shown in Figure 2.23.

Proof:

$$\begin{aligned} A \text{ NOR } A &= \overline{(A + A)} \\ &= \bar{A} \text{ Since } A + A = A \end{aligned}$$

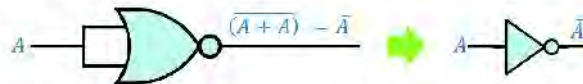


Fig 2.23 : NOT gate using NOR gate

Table 2.31 shows the proof for obtaining NOT gate using NOR gate with the help of truth table.

A	A+A	$\overline{(A + A)}$	\bar{A}
0	0	1	1
1	1	0	0

Table 2.31 : Proof using truth table

OR gate using NOR gate

We can implement an OR gate by using a NOR gate followed by another NOR gate to invert the output as shown in Figure 2.24.

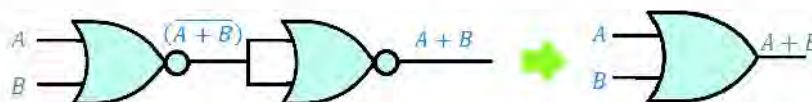


Fig 2.24: OR gate using NOR gate

Proof:

We know that $A \text{ NOR } B = \overline{(A + B)}$

$$\begin{aligned} (A \text{ NOR } B) \text{ NOR } (A \text{ NOR } B) &= \overline{(\bar{A + B})} \text{ NOR } \overline{(\bar{A + B})} \\ &= \overline{((\bar{A + B}) + (\bar{A + B}))} \end{aligned}$$

$$= ((\overline{\overline{A+B}})) \quad \text{Since } A+A=A$$

$$= A+B \quad \text{Since } (\overline{\overline{A}}) = A$$

Table 2.32 shows the proof of obtaining OR gate using NOR gate with the help of the truth table.

A	B	A+B	(A+B)	(A+B) + ($\overline{A.B}$)	(($\overline{A+B}$) . ($\overline{A+B}$))
0	0	0	1	1	0
0	1	1	0	0	1
1	0	1	0	0	1
1	1	1	0	0	1

Table 2.32 : Proof using truth table

AND gate using NOR gate

The AND gate is replaced by a NOR gate with all its inputs complemented by NOR gate inverters as shown in Figure 2.25.

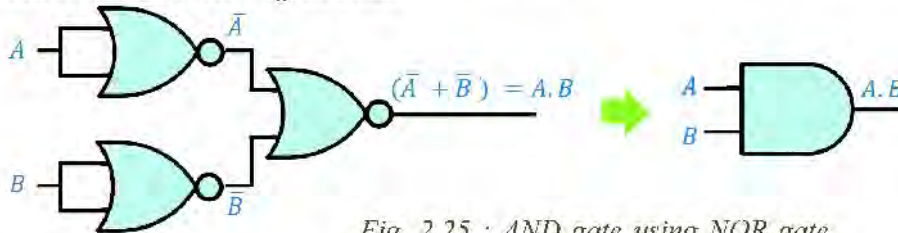


Fig. 2.25 : AND gate using NOR gate

Proof

$$A \text{ NOR } A = (\overline{A+A}) = \overline{A}$$

$$\text{Similarly, } B \text{ NOR } B = (\overline{B+B}) = \overline{B}$$

$$\begin{aligned} \text{Therefore, } (A \text{ NOR } A) \text{ NOR } (B \text{ NOR } B) &= \overline{A} \text{ NOR } \overline{B} \\ &= \overline{(\overline{A} + \overline{B})} \\ &= (\overline{\overline{A}}) \cdot (\overline{\overline{B}}) \quad \text{Since } (\overline{A+B}) = \overline{A} \cdot \overline{B} \\ &= A.B \quad \text{Since } \overline{\overline{A}} = A \end{aligned}$$

Thus, the NOR gate is also a universal gate since it can implement the AND, OR and NOT operations. Table 2.33 represents the proof for obtaining AND gate using NOR gate with the help of truth table.

A	B	\overline{A}	\overline{B}	$\overline{A+B}$	$\overline{(\overline{A+B})}$	A.B
0	0	1	1	1	0	0
0	1	1	0	1	0	0
1	0	0	1	1	0	0
1	1	0	0	0	1	1

Table 2.33 : Proof using truth table

Check yourself



1. Draw logic circuits for the Boolean expression $X + \bar{Y}$.
2. Which gates are called universal gates?
3. _____ gate produces low (0) output if any one of the input is high(1)
 (a) OR (b) AND (c) NAND (d) NOR
4. $A \text{ NAND } B =$ _____
 (a) $A+B$ (b) $A.B$ (c) $(\overline{A+B})$ (d) $(\overline{A.B})$



Let us sum up

Different methods of data representation were discussed in this chapter. Before discussing data representation of numbers, we introduced different number systems and their conversions. After the discussion of integer and floating point number representation we have mentioned different methods for character, sound, image and sound data representation. We have also discussed the concept of Boolean algebra in detail including logical operators, logic gates and laws of Boolean algebra. We concluded the chapter by introducing methods for designing basic logic circuits and by discussing the importance of universal gates in circuit designing.



Learning outcomes

After the completion of this chapter the learner will be able to

- explain the characteristics of different number systems.
- convert one number system to another.
- perform binary arithmetic.
- represent numbers and characters in computer memory.
- list the formats of sound, image and video file formats.
- identify the concept of Boolean algebra.
- explain the working of logical operators and logic gates with the help of examples.
- state and prove basic postulates and laws of Boolean algebra.
- design circuits for simple Boolean expressions.
- implement basic gates using universal gates.

Sample questions

Very short answer type

1. What is the place value of 9 in $(296)_{10}$?
2. Find octal equivalent of the decimal number 55.
3. Find missing terms in the following series
 - a) $101_2, 1010_2, 1111_2, \underline{\hspace{2cm}}, \underline{\hspace{2cm}}$
 - b) $15_8, 16_8, 17_8, \underline{\hspace{2cm}}, \underline{\hspace{2cm}}$
 - c) $18_{16}, 1A_{16}, 1C_{16}, \underline{\hspace{2cm}}, \underline{\hspace{2cm}}$
4. If $(X)_2 - (1010)_2 = (1000)_2$ then find X.
5. Name the coding system that can represent almost all the characters used in the human languages in the world.
6. Find out the logical statement(s) from the following .
 - a) Why are you late?
 - b) Will you come with me to market ?
 - c) India is my country.
 - d) Go to class room.
7. List three basic logic gates.
8. Which gate is called inverter?
9. List two complementarity Laws.
10. The Boolean expression $\overline{(A+B)}$ represents _____ gate.
 - a) AND
 - b) NOR
 - c) OR
 - d) NAND

Short answers type

1. Define the term data representation.
2. What do you mean by a number system? List any four number systems.
3. Convert the following numbers into the other three number systems:
 - a) $(125)_8$
 - b) 98
 - c) $(101110)_2$
 - d) $(A2B)_{16}$
4. Find the equivalents of the given numbers in the other three number systems.
 - a) $(71.1)_{16}$
 - b) $(207.13)_8$
 - c) 93.25
 - d) $(10111011.1101)_2$
5. If $(X)_2 = (Y)_8 = (Z)_{16} = (28)_{10}$ Then find X, Y and Z.
6. Arrange the following numbers in descending order
 - a) $(101)_{16}$
 - b) $(110)_{10}$
 - c) $(111000)_2$
 - d) $(251)_8$
7. Find X, if $(X)_2 = (10111)_2 + (11011)_2 - (11100)_2$

8. What are the methods of representing integers in computer memory?
9. Represent the following numbers in sign and magnitude method, 1's complement method and 2's complement method
a) -19 b) +49 c) -97 d) -127
10. Find out the integer which is represented as $(10011001)_2$ in sign and magnitude method.
11. Explain the method of representing a floating point number in 32 bit computer.
12. What are the methods of representing characters in computer memory?
13. Briefly explain the significance of Unicode in character representation.
14. Match the following:

A	B
i) If any input is 1 output is 1	a) NAND
ii) If an input is 0 output is 0	b) OR
iii) If any input is 0 output is 1	c) NOR
iv) If any input is 1 output is 0	d) AND

15. Find dual of following Boolean expressions
a) $X.Y+Z$ b) $A.C+A.1+A.C$ c) $(A+0).(A.1.\bar{A})$
16. Find complement of following Boolean expressions
a) $\bar{A} \bar{B}$ b) $\overline{A.B} + \overline{C.D}$
17. Construct logic circuit for the following Boolean expression.
(i) $\bar{a}\bar{b} + c$ (ii) $ab + \bar{a}\bar{b} + \bar{a}b$ (iii) $(a + \bar{b}).(\bar{a} + \bar{b})$
18. Why are NAND and NOR gates called universal gates? Justify with an example.

Long answer type

1. Briefly explain different methods for representing numbers in computer memory.
2. Briefly explain different methods for representing characters in computer memory.
3. What are the file formats for storing image, sound and video data?
4. Give logic symbol, Boolean expression and truth table for three input AND gate.
5. Prove that NOR gate is a universal gate by implementing all the basic gates.

Key concepts

- **Data processing**
- **Functional units of a computer**
- **Hardware**
 - Processors
 - Motherboard
 - Memory - primary storage, secondary storage
 - Use of memory in computer
 - Input output devices
- **e-Waste**
 - Disposal methods
 - Green computing
- **Software**
 - System software (operating system, language processors, utility software)
 - Application software (general purpose, specific purpose)
 - Free software and open source software
 - Freeware and shareware
 - Proprietary software
- **Humanware / Liveware**

Components of the Computer System

We are familiar with computers and their uses in today's world. Computer can be defined as a fast electronic device that accepts data, processes it as per stored instructions and produces information as output. This chapter presents an overview of the basic design of a computer system: how the different parts of a computer system are organised and various operations are performed to do a specific task. We know that a computer has two major components - hardware and software. Hardware refers to all physical components associated with a computer system while software is a set of instructions for the hardware to perform a specific task. When we use computers to solve any problem in real life situations, we define the tasks required to process data for generating information. This chapter presents the concepts of data processing at first and discusses how the functional units of a computer help data processing. Then various hardware components are presented followed by electronic waste, its disposal methods and the concept of green-computing. A detailed classification of software is listed along with different types of computer languages. We will also discuss the concepts of open source, freeware, shareware and proprietary software.

3.1 Data processing

Data processing refers to the operations or activities performed on data to generate information. Data denotes raw facts and figures such as numbers, words, amount, quantity, etc. that can be processed or manipulated. Information is a meaningful and processed form of data. It adds to our knowledge and helps in making decisions. Data processing proceeds through six stages as in Figure 3.1.

- (a) Capturing data
- (b) Input of data
- (c) Storage of data
- (d) Processing / manipulating data
- (e) Output of information
- (f) Distribution of information

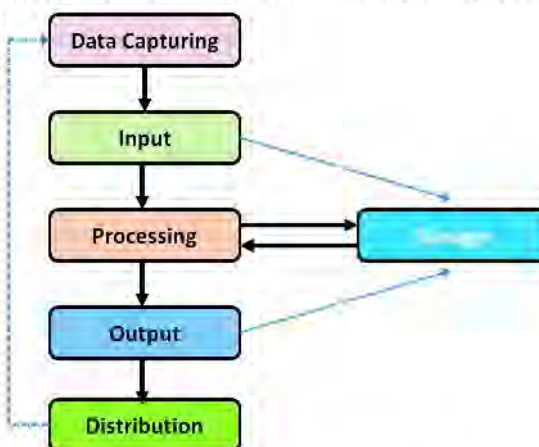


Fig. 3.1 : Data processing stages

Let us take a close look at these stages.

Capturing Data: This is the first stage in data processing. Here a proforma, known as the source document, is designed to collect data in proper order and format. This document is used for data collection.

Input: In this stage, the data collected through the source documents is fed to the computer for processing. But now a days, in many cases, the data are directly fed into the computer without using source documents.

Storage: In data processing, the input data are stored before processing. The information obtained after processing may also be stored.

Process: The data stored in computers is retrieved for processing. Various operations like calculation, classification, comparison, sorting, filtering, summarising, etc. may be carried out as part of processing.

Output: The processed data is obtained in this stage in the form of information. The output may be stored for future reference as it may be used for generating some other information in another context.

Distribution of information: The information obtained from the output stage is distributed to the beneficiaries. They take decisions or solve problems according to the information.

We have seen the activities involved in data processing. Computers are designed in such a way that it can be involved in these activities. Let us see how the functional units of a computer are organised.

3.2 Functional units of a computer

Even though computers differ in size, shape, performance and cost over the years, the basic organisation of a computer is the same. As we discussed in Chapter 1, it is based on a model proposed by John Von Neumann, a mathematician and computer scientist. It consists of a few functional units namely, Input Unit, Central Processing Unit, Storage Unit and Output Unit as shown in Figure 3.2. Each of these units is assigned to perform a particular task. Let us discuss the functions of these units.

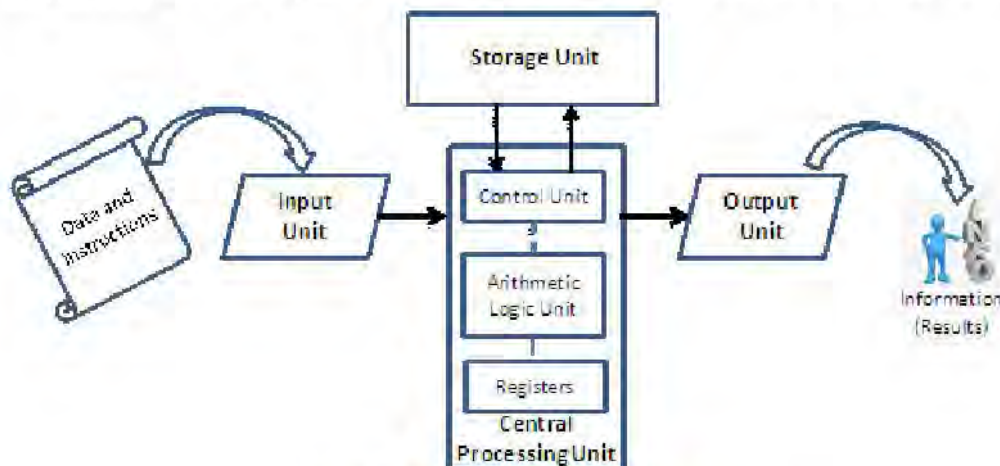


Fig. 3.2 : Basic organisation of computer

a. Input unit

The collected data and the instructions for their processing are entered the computer through the input unit. They are stored in the memory (storage unit). The data may be in different forms like number, text, image, audio, video, etc. A variety of devices are available to input the data depending on its nature. Keyboard, mouse, scanner, mic, digital camera, etc. are some commonly used input devices. In short, the functions performed by input unit are as follows:

1. Accepts instructions and data from the outside world.
2. Converts these instructions and data into a form acceptable to the computer.
3. Supplies the converted instructions and data to the computer for processing.

b. Central Processing Unit (CPU)

The CPU is the brain of the computer. In a human body, all major decisions are taken by the brain, and other parts of the body function as directed by the brain. Similarly, in a computer system, all major calculations and comparisons are made inside the CPU. It is also responsible for activating and controlling the operations of other units of the computer. The functions of CPU are performed by three components - Arithmetic Logic Unit (ALU), Control Unit (CU) and Registers.

i. Arithmetic Logic Unit (ALU)

The actual operations specified in the instructions are carried out in the Arithmetic Logic Unit (ALU). It performs calculations and logical operations such as comparisons and decision making. The data and instructions stored in the storage unit are transferred to the ALU and the processing takes place in it. Intermediate results produced by the ALU are temporarily transferred back to the storage and are retrieved later when needed for further processing. Thus there is a data flow between the storage and the ALU many times before the entire processing is completed.

ii. Control Unit (CU)

Each of the functional units has its own function, but none of these will perform the function until it is asked to. This task is assigned to the control unit. It invokes the other units to take charge of the operation they are associated with. It is the central nervous system that manages and coordinates all other units of the computer. It obtains instructions from the program stored in the memory, interprets the operation and issues signals to the unit concerned in the system to execute them.

iii. Registers

These are temporary storage elements that facilitate the functions of CPU. There are variety of registers; each is designated to store unique items like data, instruction, memory address, results, etc.

c. Storage unit

The data and instructions entered in the computer through input unit are stored inside the computer before actual processing starts. Similarly, the information or results produced after processing are also stored inside the computer, before transferring to the output unit. Moreover, the intermediate results, if any, must also be stored for further processing. The storage unit of a computer serves all these purposes. In short, the specific functions of storage unit are to hold or store:

1. Data and instructions required for processing.
2. Intermediate results for ongoing processing.
3. Final results of processing, before releasing to the output unit.

The storage unit comprises of two types of storages as detailed below:

- i. **Primary storage:** It is also known as main memory. It is again divided into two – Random Access Memory (RAM) and Read Only Memory (ROM). RAM holds instructions, data and intermediate results of processing. It also holds the recently produced results of the job done by the computer. ROM contains instructions for the start up procedure of the computer. The Central Processing

Unit can directly access the main memory at a very high speed. But it has limited storage capacity.

- ii. **Secondary storage:** It is also known as auxiliary storage and it takes care of the limitations of primary storage. It has huge storage capacity and the storage is permanent. Usually we store data, programs and information in the secondary storage, but we have to give instruction explicitly for this. Hard disk, CDs, DVDs, memory sticks, etc. are some examples.

d. Output unit

The information obtained after data processing is supplied to the outside world through the output unit in a human-readable form. Monitor and printer are the commonly used output devices. The functions performed by output unit can be concluded as follows:

1. Receives the results produced by the CPU in coded form.
2. Converts these coded results to human-readable form.
3. Supplies the results to the outside world.

3.3 Hardware

We know that a computer system consists of hardware and software. The term hardware represents the tangible and visible parts of a computer, which consists of some electro mechanical components. These hardware components are associated with the functional units of a computer. Let us discuss some of these components.

3.3.1 Processors

In the previous section, we learned that CPU (Central Processing Unit) is responsible for all computing and decision making operations and coordinates the working of a computer. The performance of a CPU determines the overall performance of the computer. Since CPU is an Integrated Circuit (IC) package which contains millions of transistors and other components fabricated into a single silicon chip, it is also referred as microprocessor. Figure 3.3 shows the processors developed by some manufacturers. A CPU is usually plugged into a large socket on the main circuit board (the motherboard) of the computer. Since heat is generated when the CPU works, a proper cooling system is provided with a heat sink and fan. The commonly used processors are Intel core i3, core i5, core i7, AMD Quadcore, etc.

Registers are storage locations inside the CPU, whose contents can be accessed more quickly by the CPU than



Fig. 3.3 : Different Processors



Every computer contains an internal clock that regulates the rate at which instructions are executed. The CPU requires a fixed number of clock ticks (or clock cycles) to execute each instruction. The faster the clock, the more the instructions the CPU can execute per second. Another factor is the architecture of the chip. The number of bits the processor can process at one time is called word size. Processors with many different word sizes exist: 8-bit, 16-bit, 32-bit, 64-bit, etc.

other memory. Registers are temporary storage areas for instructions or data. They are not a part of memory; rather they are special additional storage locations that offer the advantage of speed. Registers work under the direction of the control unit to accept, hold and transfer instructions or data and perform arithmetic or logical operations at high speed. It speeds up the execution of programs. Important registers inside a CPU are:

- i. **Accumulator:** The accumulator is a part of the arithmetic/logic unit (ALU). This register is used to store intermediate result while performing arithmetic and logical operations. It is also called register A.
- ii. **Memory Address Register (MAR):** It stores the address of a memory location to which data is either to be read or written by the processor.
- iii. **Memory Buffer Register (MBR):** It holds the data, either to be written to or read from the memory by the processor.
- iv. **Instruction Register (IR):** The instructions to be executed by the processor are stored in the Instruction Register.
- v. **Program Counter (PC):** It holds the address of the next instruction to be executed by the processor.

3.3.2 Motherboard

A motherboard is a large Printed Circuit Board (PCB) to which all the major components including the processor are integrated. It also provides expansion slots for adding additional circuit boards like memory, graphics card, sound card, etc. (refer Figure 3.4). The motherboard must be compatible with the processor chosen.

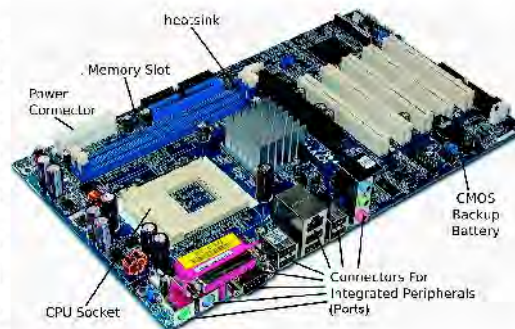


Fig. 3.4 : Motherboard

3.3.4 Peripherals and ports

Peripherals are devices that are attached to a computer system to enhance its capabilities. Ports on the motherboard are used to connect external devices. Peripherals include input and output devices, external storage and communication devices. These devices communicate with the motherboard through the ports like VGA, PS/2, USB, Ethernet, HDMI, etc. that are available on the motherboard. Figure 3.5 shows some ports used in personal computers.

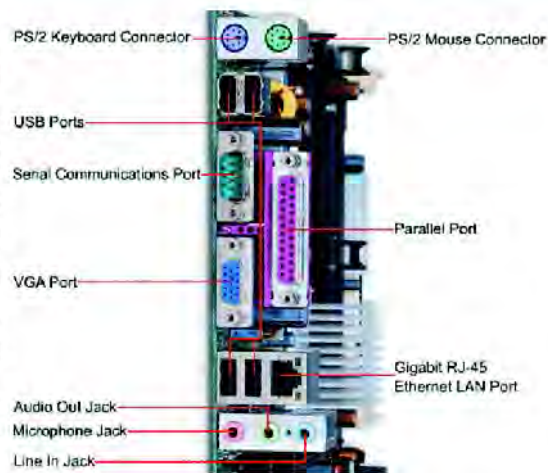


Fig. 3.5 : Ports

3.3.5 Memory

Memory is a place where we can store data, instructions and results temporarily or permanently. Memory can be classified into two - primary memory and secondary memory. Primary memory holds data, intermediate results and results of ongoing jobs temporarily. Secondary memory, on the other hand, holds data and information permanently. Before learning more about memory, let us discuss the different memory measuring units. The measuring units are:

Binary Digit = 1 Bit	1 MB (Mega Byte) = 1024 KB
1 Nibble = 4 Bits	1 GB (Giga Byte) = 1024 MB
1 Byte = 8 Bits	1 TB (Tera Byte) = 1024 GB
1 KB (Kilo Byte) = 1024 Bytes	1 PB (Peta Byte) = 1024 TB

a. Primary storage

Primary memory is a semiconductor memory that is accessed directly by the CPU. It is capable of sending and receiving data at high speed. This includes mainly three types of memory such as RAM, ROM and cache memory.

i. Random Access Memory (RAM)

RAM, shown in Figure 3.6 refers to the main memory that microprocessor can read from and write into. Data can be stored and retrieved at random from anywhere within the RAM, no matter where the data is. Data or instructions to be processed by the CPU must be placed in the RAM. The contents of RAM are lost when power is switched off. Therefore, RAM is a volatile memory. Storage capacity of RAM is 2 GB and above.

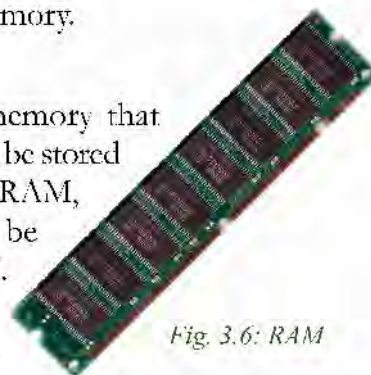


Fig. 3.6: RAM

The speed of a RAM refers to how fast the data in memory is accessed. It is measured in Mega Hertz (MHz). When a computer is in use, its RAM contains the following:

1. The operating system software.
2. The application software currently being used.
3. Any data that is being processed.

ii. Read Only Memory (ROM)

ROM is a permanent memory that can perform only read operations and its contents cannot be easily altered. ROM is non-volatile; the contents are retained even after the power is switched off. ROM, shown in Figure 3.7, is used in most computers to hold a small, special piece of 'boot up' program known as Basic Input Output System (BIOS). This software runs when the computer is switched on or 'boots up'. It checks the computer's hardware and then loads the operating system. There are some modified types of ROM that include:

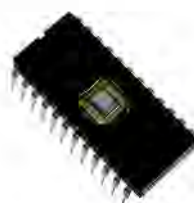


Fig.: 3.7 : ROM Chip

1. PROM - Programmable ROM which can be programmed only once.
2. EPROM - Erasable programmable ROM that can be rewritten using ultra violet radiation.
3. EEPROM - Electrically Erasable Programmable ROM which can be rewritten electrically.

Table 3.1 shows the comparison between RAM and ROM.

RAM	ROM
<ul style="list-style-type: none"> • It is faster than ROM. • It stores the operating system, application programs and data when the computer is functioning. • It allows reading and writing. • It is volatile, i.e. its contents are lost when the device is powered off. 	<ul style="list-style-type: none"> • It is a slower memory. • It stores the program required to boot the computer initially. • Usually allows reading only. • It is non-volatile, i.e. its contents are retained even when the device is powered off.

Table 3.1 : RAM - ROM comparison

iii. Cache memory

Cache memory is a small and fast memory between the processor and RAM (main memory). Frequently accessed data, instructions, intermediate results, etc. are stored in cache memory for quick access. When the processor needs to read from or write

to a location in RAM, it first checks whether a copy of that data is in the cache. If so, the processor immediately reads the cache, which is much faster than reading from the RAM. Cache is more expensive than RAM, but it is worth getting a CPU and motherboard with built-in cache in order to maximise system performance.

b. Secondary or Auxiliary storage

Secondary memory is permanent in nature. Unlike the contents of RAM, the data stored in these devices does not vanish when power is turned off. Secondary memory is much larger in size than RAM, but is slower. It stores programs and data but the processor cannot access them directly. Secondary memory is also used for transferring data or programs from one computer to another. It can also act as a backup. The major categories of storage devices are magnetic, optical and semiconductor memory.

i. Magnetic storage devices

Magnetic storage devices use plastic tape or metal/plastic disks coated with magnetic materials. Data is recorded magnetically in these devices. Read/write heads are used to access data from these devices. Some of the popular magnetic storage devices are magnetic tapes, hard disks, etc.

ii. Optical storage devices

Optical disk is a data storage medium which uses low-powered laser beam to read and write data into it. It consists of an aluminum foil sandwiched between two circular plastic disks. Data is written on a single continuous spiral in the form of pits and lands. The laser beam reads this pits and lands as 0s and 1s. Optical disks are very cheap to produce in large quantities and are popular secondary storage media. The main types of optical disks are CD, DVD and Blu-Ray.

iii. Semi-conductor storage (Flash memory)

Flash drives use EEPROM chips for data storage. They do not contain any moving parts and hence they are shockproof. Flash memory is faster and durable when compared to other types of secondary memory. The drawback is that they are limited to a certain number of write cycles. The different variants of flash memories are USB flash drives and flash memory cards. Figure 3.8 shows different types of flash memories.



Fig. 3.8: Flash drive and memory cards



To see how registers, primary memory and secondary storage work together in a computer, let us use the analogy of making a salad in our kitchen. Suppose we have:

- A refrigerator where we store vegetables for the salad
- A counter where we place all vegetables before putting them on the cutting board for chopping.
- A cutting board on the counter where we chop vegetables.
- A recipe that details what vegetables to chop.
- The corners of the cutting board are kept free for partially chopped piles of vegetables that we intend to chop more or to mix with other partially chopped vegetables.
- A bowl on the counter where we mix and store the salad.
- Space in the refrigerator to put the mixed salad after it is made.

The process of making the salad is then: bring the vegetables from the fridge to the counter top; place some vegetables on the chopping board according to the recipe; chop the vegetables, possibly storing some partially chopped vegetables temporarily on the corners of the cutting board; place all the chopped vegetables in the bowl and keep it back in the fridge if not served on the dinner table.



In this context the refrigerator serves as secondary (hard disk) storage. It can store high volumes of vegetables for long periods of time. The counter top functions like the computer's motherboard - everything is done on the counter (inside the computer). The cutting board is the ALU - the work gets done there. The recipe is the control unit - it tells you what to do on the cutting board (ALU). Space on the counter top is the equivalent of RAM - all required vegetables must be brought from the fridge and placed on the counter top for fast access. Note that the counter top (RAM) is faster to access than the fridge (disk), but cannot hold as much, and cannot hold it for long periods of time. The corners of the cutting board where we temporarily store partially chopped vegetables are equivalent to the registers. The corners of the cutting board are very fast to access for chopping, but cannot hold much. The salad bowl is like a cache memory, it is for storing chopped vegetables to be temporarily removed from the corners of the cutting board (as there is too much) or the salad waiting to be taken back to the fridge (putting data back on a disk) or to the dinner table (outputting the data to an output device).

3.3.6 Role of memories in computers

Let us consider the case of a payroll program to calculate the salary of an employee. The data for all the employees is available in the hard disk. All the data about a particular employee is taken to the RAM and from there data related to salary calculation - bonuses, deductions, etc. is taken to the cache. The data representing the hours worked and the rate of pay is moved to their respective registers. Using data on the hours worked and the rate of pay, ALU makes calculations based on instructions from control unit. For further calculations, it moves the overtime hours, bonuses, etc. from cache to registers. As the CPU finishes calculations about one employee, the data about the next employee is brought from secondary storage into RAM, then cache and eventually into the registers.

Figure 3.9 depicts the hierarchy of different memories according to the storage capacity and access speed.

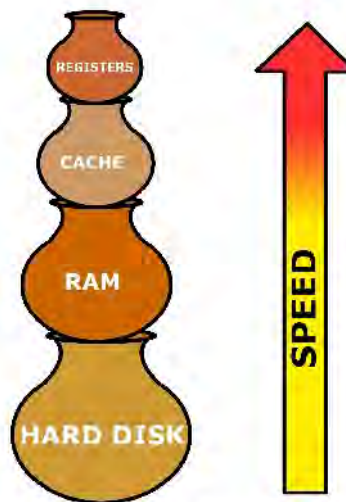


Fig. 3.9 : Memory hierarchy

Table 3.2 summarises the characteristics of various kinds of data storage in the storage hierarchy.

Storage	Speed	Capacity	Relative Cost	Volatile
Registers	Fastest	Lowest	Highest	Yes
Cache	More Fast	Low	Very High	Yes
RAM	Very Fast	Low/Moderate	High	Yes
Hard Disk	Moderate	Very High	Very Low	No

Table 3.2 : Comparison of different characteristics of various types of memories








Check yourself






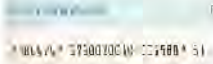



1. The fastest memory in a computer is _____.
2. Define data processing.
3. What is cache memory?
4. What is the use of program counter register?
5. What is the use of ALU?

3.3.7 Input/Output devices

The computer will be of no use unless it is able to communicate with the outside world. Input/output devices are required for users to communicate with the computer. In simple terms, input devices feed data and instructions into the computer and output devices presents information from a computer system. These input/output devices are connected to the CPU through various ports or with the help of wireless technology. Since they reside outside the CPU, they are called peripherals. The following table shows various **input devices** and their uses.

Device	Features / Uses
Keyboard 	Allows the user to input text data consisting of alphabets, numbers and other characters. Detects the key pressed and generates the corresponding ASCII code which can be recognised by the computer. Wired and wireless keyboards are available.
Mouse 	A small handheld device used to position the cursor or move the pointer on the computer screen by rolling it over a mouse pad / flat surface. Different types of mouse are ball, optical and laser mouse. Wireless mouse is also available.
Light pen 	A pointing device shaped like a pen. It has the advantage of 'drawing' directly onto the screen. Used by engineers, artists, fashion designers for Computer Aided Designing (CAD) and drawing purposes.
Touch screen 	Allows the user to operate/make selections by simply touching on the display screen. It can also be operated using a stylus which gives more precision.
Graphic tablet 	Consists of an electronic writing area and a special 'pen' that works with it. Allows artists to create graphical images with actions similar to traditional drawing tools.
Joystick 	Used to playing video games, control training simulators and robots. Has a vertical stick which can move in any direction and a button on top that is used to select the option pointed by the cursor.
Microphone 	Accepts sound which is analogue in nature as input and converts it to digital format. The digitised sound can be stored in the computer for later processing or playback.

Scanner 	<p>Allows capturing of information, like pictures or text and converting it into a digital format that can be edited using a computer. Quality of the image depends on the resolution of the scanner. Different variants of scanners are flat bed, sheet feed and hand held scanner. Optical Character Recognition (OCR) software is used to recognise the text in an image scanned and convert it into text, which can be edited by a text editor.</p>
Optical Mark Reader (OMR) 	<p>Another scanning device that reads predefined positions and records where marks are made on the printed form. Useful for applications in which large numbers of hand-filled forms need to be processed quickly with great accuracy, such as objective type tests and questionnaires.</p>
Barcode/Quick Response (QR) code reader   	<p>A bar code is a set of vertical lines of different thicknesses and spacing that represent a number. Barcode readers are used to input data from such set of barcodes. Hand-held scanners, mobile phones with camera and special software are used as barcode readers. QR (Quick Response) code is similar to barcodes. Barcodes are single dimensional where as QR codes are two dimensional. The two dimensional way of storing data allows QR code to store more data than a standard barcode. This code can store website URLs, plain text, phone numbers, email addresses and any other alphanumeric data. The QR code can be read using a barcode reader or a mobile with a camera and special software installed.</p>
Magnetic Ink Character Recognition (MICR) Reader  	<p>MICR readers are used in banks for faster electronic clearing of cheques. The lower portion of a cheque contains cheque number, branch code, bank code, etc. printed in a special font using an ink containing iron oxide particles. Iron oxide has magnetic properties. MICR reader can easily recognise these characters by magnetically charging them while scanning. This MICR data along with the image of the cheque is send to the cheque drawer's (the person who issues the cheque) branch to transfer the amount. This reduces errors in data entry and speeds up money transfer.</p>
Biometric sensor 	<p>Identifies unique human physical features with high accuracy. It is an essential component of a biometric system which uses physical features like fingerprints, retina, iris patterns, etc. to identify, verify and authenticate the identity of the user.</p>





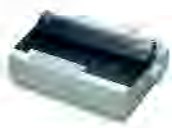

Smart card reader 	Smart card is a plastic card that stores and transacts data. It may contain a memory or a micro processor. Used in banking, healthcare, telephone calling, electronic cash payments and other applications. These are used to access data in a smart card.
Digital camera 	Takes pictures and videos and converts it to the digital format. The images are stored in the memory and can be transferred to computer. Web camera is a compact and less expensive version of a digital camera. It is used in computers for video calling, video chatting, etc. It does not have an internal memory.

Table 3.3 : Input devices and their uses

Now let us see some **output devices** and their features. Table 3.4 shows various output devices and their uses.

Device	Features / Uses
Visual Display Unit (VDU) 	Display devices include CRT monitors, LCD monitors, TFT monitors, LED monitors, gas plasma monitors, Organic Light Emitting Diode (OLED) Monitors, etc. Information shown on a display device is called soft copy. The size of a monitor is measured diagonally across the screen, in inches.
LCD projector 	An LCD projector is a type of video projector for displaying video, images or computer data on a large screen or other flat surface. A beam of high-intensity light which travels through thousands of shifting pixels in an LCD is focused by a lens on the surface.
Printer  	Used to produce hardcopy output. The output printed on paper is known as hardcopy. Classified as Impact or Non-impact printers. Dot-matrix uses impact mechanism. It can print carbon copies with less printing cost. Speed is measured in number of characters printed in a unit of time and is represented as characters per second (cps), lines per minute (lpm) or pages per minute (ppm). These printers are slow and noisy. Inkjet printers are non-impact printers that form the image on the page by spraying tiny droplets of ink from the print head. Ink jet printers are inexpensive, but the cost of ink cartridges makes them costly to operate in the long run. Laser printers are non-impact printers that




	<p>produce good quality images. Monochrome and color laser printers are available. Color laser printers use multiple color toner cartridges to produce color output and are expensive. Laser printers are faster and their speed is rated in pages per minute (ppm). Thermal printer is a non-impact printer that produces a printed image by selectively heating heat sensitive thermal paper when it passes over the thermal print head. The coating turns black in the areas where it is heated, producing an image. It is popular as a portable printer.</p>
<p>Plotter</p> 	<p>A plotter is an output device used to produce hardcopies of graphs and designs on the paper. A plotter is typically used to print large-format graphs or maps such as construction maps, engineering drawings and big posters. Plotters are of two types: Drum plotters and Flatbed plotters. A drum plotter is also known as Roller plotter. A flatbed plotter is also known as Table plotter.</p>
<p>3D printer</p> 	<p>A 3D printer is an output device used to print 3D objects. It can produce different kinds of objects, in different materials, using the same printer. The 3D printing process turns the object to be printed, into thousands of tiny little slices. It then prints it from the bottom to top, slice by slice. Those tiny layers stick together to form a solid object.</p>
<p>Audio output device</p> 	<p>The audio output is the ability of the computer to produce sound. Speakers are the output devices that produces sound. It is connected to the computer through audio ports.</p>

Table 3.4 : Output devices and their uses

We have seen different types of printers. Table 3.5 shows a comparison on various characteristics of these printers.

Features	Laser Printers	Inkjet Printers	Thermal Printers	Dot Matrix Printers
Printing material used	Ink powder	Liquid ink	Heat sensitive paper	Ink soaked ribbon
How it prints	It fuses the powder on the paper through heating.	It sprays liquid ink on paper through microscopic nozzles.	Thermal paper is passed over the thermal print head.	Pins are pushed against ribbon on paper.

Printing speed	20 pages per minute	6 pages per minute	150 mm per second	30-550 characters per second
Quality	Printing quality is good. Best for black and white.	Printing quality is good, especially for smaller fonts.	Poor quality printing of images. Good quality text printing.	Poor printing quality for images. In terms of text, printing is good.
Advantages	Quiet, prints faster, high print quality.	Quiet, high print quality, no warm up time, device cost is less.	Quiet, fast, smaller, lighter, consume less power and portable.	Cheaper to print as ribbon is cheap. Carbon copy possible.
Disadvantages	More susceptible to paper jams. Toner is expensive. Device itself is expensive.	Ink is expensive, ink is not waterproof and nozzle is prone to clogging.	Requires special thermal quality paper. Poor quality printing.	Initial purchase is expensive, prints are not fast, makes noise.

Table 3.5 : Comparison of printers

3.4 e-Waste

e-Waste refers to electronic products nearing the end of their 'useful life'. Electronic waste may be defined as discarded computers, office electronic equipment, entertainment devices, mobile phones, television sets and refrigerators. The used electronics which are destined for reuse, resale, salvage, recycling or disposal are also considered as e-waste.

Nowadays electronics is part of modern life – desktops, laptops, cell phones, refrigerators, TVs and a growing number of other gadgets. Every year we buy new, updated equipments to satisfy our needs. More than 300 million computers and one billion cell phones are produced every year. All of these electronics goods become obsolete or unwanted, often, within two or three years of purchase. This global mountain of waste is expected to continue growing at 8% per year.

Rapid changes in technology, changes in media, falling prices and planned obsolescence have resulted in a fast-growing surplus of electronic waste around the globe. It is estimated that 50 million tons of e-Waste are produced each year. Only 15-20% of e-Waste is recycled, the rest of these materials go directly into landfills and incinerators. Sale of electronic products in countries such as India and China and across continents such as Africa and Latin America are set to rise sharply over the next 10 years.

3.4.1 Why should we be concerned about e-Waste?

Electronic waste is not just waste. It contains some very toxic substances, such as mercury, lead, cadmium, brominated flame retardants, etc. The toxic materials can cause cancer, reproductive disorders and many other health problems, if not properly managed. It has been estimated that e-Waste may be responsible for up to 40% of the lead found in landfills. Important hazardous chemicals, their sources and consequences are listed in Table 3.6.

Chemical	Source	Consequence
Lead	Found as solder on printed circuit boards and in computer monitor glass.	Lead can cause damage to the central and peripheral nervous systems, blood systems and kidneys in humans.
Mercury	Found in printed circuit boards, LCD screen backlights.	Affect a baby's growing brain and nervous system. Adults can suffer organ damage, mental impairment and a variety of other symptoms.
Cadmium	Found in chip resistors and semiconductors.	Cause various types of cancer. Cadmium can also accumulate in the kidney and harm it.
BFRs-Brominated Flame Retardants	Found in printed circuit boards and some plastics.	These toxins may increase the risk of cancer.

Table 3.6 : Hazardous chemicals, its source and consequence

3.4.2 What happens to the e-Waste?

Unfortunately, an incredibly small percentage of e-waste is recycled. Even when we take it to a recycling center it is often not actually recycled – in the way most of us expect. CRTs have a relatively high concentration of lead and phosphors both of which are necessary for the display. The United States Environmental Protection Agency (EPA) includes discarded CRT monitors in its category of 'hazardous household waste'.

The majority of e-Waste is most often dumped or burned – either in formal landfills and incinerators or informally dumped or burned. These inappropriate disposal methods for electronic waste fail to reclaim valuable materials or manage the toxic materials safely. In effect, our soil, water and air are easily contaminated.

e-Wastes should never be disposed with garbage and other household wastes. This should be segregated at



Fig. 3.10 : Defective and obsolete electronic items

the site and sold or donated to various organisations. Considering the severity of the e-Waste problem, it is necessary that certain management options be adopted by government, industries and the public to handle the bulk e-Wastes.

Realising the growing concern over e-Waste, Central Pollution Control Board (CPCB) of Government of India has formulated 'The e-Waste (Management & Handling) Rules, 2011' and are effective from 01-05-2012. These rules shall apply to every producer, consumer, collection centre, dismantler and recycler of e-Waste involved in the manufacture, sale and processing of electrical and electronic equipment or components. The implementation and monitoring of these guidelines shall be done by the State Pollution Control Boards concerned.

Government of Kerala has introduced strict measures for safe collection and disposal of e-Waste through a government order. The government has defined the role of manufacturers, local bodies and the Pollution Control Board (PCB) in safe disposal of e-Waste. Under the Extended Producer Responsibility, manufacturers of electrical and electronic goods will be required to take back used products from consumers directly or through agents or introduce buyback arrangement. They will also have to supply the e-Waste to authorised recycling units. Consumers have been directed to return used products of known brands to the manufacturers or deposit them at the collection centres set up by local bodies. The PCB will be required to identify agencies for recycling or disposal of e-Waste and organise awareness programmes on e-Waste disposal.

3.4.3 e-Waste disposal methods

The following methods can be used for disposing e-Waste.

- a. **Reuse:** It refers to second-hand use or usage after the equipment has been upgraded or modified. Most of the old computers are passed on to relatives/friends or returned to retailers for exchange or for money. Some computers are also passed on to charitable institutions, educational institutions, etc. Inkjet cartridges and laser toners are also used after refilling. This method reduces the volume of e-Waste generation.
- b. **Incineration:** It is a controlled and complete combustion process in which the waste is burned in specially designed incinerators at a high temperature in the range of 900 to 1000 degree Celsius.
- c. **Recycling of e-Waste:** Recycling is the process of making or manufacturing new products from a product that has originally served its purpose. Monitors, keyboards, laptops, modems, telephone boards, hard drives, compact disks, mobiles, fax machines, printers, CPUs, memory chips, connecting wires and cables can be recycled.
- d. **Land filling:** It is one of the widely used but not recommended method for the disposal of e-Waste.

Role of students in e-Waste disposal

- Stop buying unnecessary electronic equipments.
- When electronic equipments get faulty try to repair it instead of buying a new one.
- Try to recycle electronic equipments by selling them or donating them to others extending their useful life and keeping them out of the waste stream.
- If you really need to buy new electronics, choose items with less hazardous substances, greater recycled content, higher energy efficiency, longer life span, and those that will produce less waste.
- Visit the manufacturer's website or call the dealer to find out if they have a take back programme or scheme for your discarded electronics.
- If the device is battery-operated, buy rechargeable instead of disposable batteries.
- Buy products with good warranty and take back policies.

3.4.4 Green computing or Green IT

Green computing is the study and practice of environmentally sustainable computing or IT. Green computing is the designing, manufacturing, using and disposing of computers and associated components such as monitors, printers, storage devices, etc., efficiently and effectively with minimal or no impact on the environment.

One of the earliest initiatives towards green computing was the voluntary labelling program known as 'Energy Star'. It was conceived by the Environmental Protection Agency (EPA) in 1992 to promote energy efficiency in hardware of all kinds. The Energy Star label has become a common sight, especially in notebook computers and displays. Similar programmes have been adopted in Europe and Asia. The commonly accepted Energy Star symbol is shown in Figure 3.11.

Government regulation is only a part of an overall green computing idea. The work habits of computer users and business firms have to be modified to minimise adverse impact on the global environment. Here are some steps that can be taken:



Fig. 3.11 : Energy Star label

- Turn off computer when not in use.
- Power-on the peripherals such as laser printers only when needed
- Use power saver mode.
- Use laptop computers rather than desktop computers whenever possible.
- Take printouts only if necessary.
- Use liquid crystal display (LCD) monitors rather than cathode ray tube (CRT) monitors.
- Use hardware/software with Energy Star label.
- Dispose e-Waste according to central, state and local regulations.
- Employ alternative energy sources like solar energy.

The environmentally responsible and eco-friendly use of computers and their resources is known as green computing.

How to make computers green?

The features that are important in making a computer greener include size, efficiency and materials. Smaller computers are greener because they use fewer materials and require less electricity to run. Efficient use of energy is also an important component of a green computer. Smaller computers such as laptops are more energy-efficient than bigger models and LCD screens use much less energy than the older CRT models. The use of hazardous materials such as lead and mercury should be minimised.

To promote green computing the following four complementary approaches are employed:



Green design: Designing energy-efficient and eco-friendly computers, servers, printers, projectors and other digital devices.

Green manufacturing: Minimising waste during the manufacturing of computers and other components to reduce the environmental impact of these activities.

Green use: Minimising the electricity consumption of computers and peripheral devices and using them in an eco-friendly manner.

Green disposal: Reconstructing used computers or appropriately disposing off or recycling unwanted electronic equipment.

Check yourself



1. The environmentally responsible and eco-friendly use of computers and their resources is known as _____.
2. The process of making or manufacturing new products from the product that has originally served its purpose is called _____.
3. The labelling programme to promote energy efficiency in computers and their resources is called _____.
4. List any two input and output devices each.



Let us do

1. Conduct a survey in your locality to study the impact of e-Waste on the environment and health of the people and write a report.
2. Discuss the importance of green computing.

3.5 Software

Software is a general term used to denote a set of programs that help us to use the computer system and other electronic devices efficiently and effectively. If hardware is said to form the body of a computer system, software is its mind or soul. There are two types of software:

- System software
- Application software

3.5.1 System software

It is a set of one or more programs designed to control the operations of a computer. They are general programs designed to assist humans in the use of computer system by performing tasks such as controlling the operations, move data into and out of a computer system and to do all the steps in executing application programs. In short, system software supports the running of other software, its communication with other peripheral devices. It helps users to use computer in an effective manner. It implies that system software helps to manage resources of the computer. Figure 3.12 depicts how system software interfaces between user and hardware.

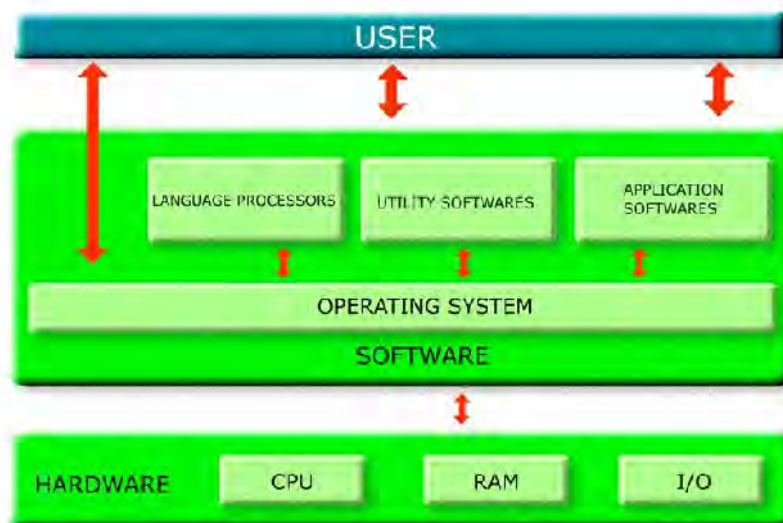


Fig.3.12: Software with user and hardware interface

System software is a set of system programs which aids in the execution of a general user's computational requirements on a computer system. The following are the components of system software:

- a. Operating system
- b. Language processors
- c. Utility software

a. Operating system

Operating system is a set of programs that acts as an interface between the user and computer hardware. The primary objective of an operating system is to make the computer system convenient to use. Operating system provides an environment for user to execute programs. It also helps to use the computer hardware in an efficient manner.

Operating system controls and co-ordinates the operations of a computer. It acts as the resource manager of the computer system as shown in Figure 3.13. Operating system is the most important system software. It is the first program to be loaded from hard disk in the computer and it resides in the memory till the system is shut down. It tries to prevent errors and the improper use of computer.

The major functions of an operating system are process management, memory management, file management, security management and command interpretation.

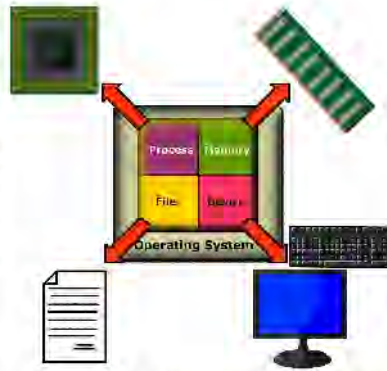


Fig. 3.13 : Operating System as a resource manager

i. Process management

By the term process we mean a program in execution. The process management module of an operating system takes care of the allocation and deallocation of processes and scheduling of various system resources to the different requesting processes.

ii. Memory management

Memory management is the functionality of an operating system which handles or manages primary memory. It keeps track of each and every memory location whether it is allocated to some process or it is free. It calculates how much memory is to be allocated to each process and allocates it. It de-allocates memory if it is not needed further.

iii. File management

The file management module of an operating system takes care of file related activities such as organising, naming, storing, retrieving, sharing, protection and recovery.

iv. Device management

Device management module of an operating system performs the management of devices attached to the computer. It handles the devices by combining both hardware

and software techniques. The OS communicates with the hardware device via the device driver software. Examples of various operating systems are DOS, Windows, Unix, Linux, Mac OS X, etc.

b. Language processors

We know that natural languages are the medium of communication among human beings. Similarly, in order to communicate with the computer, the user also needs to have a language that should be understood by the computer. Computer languages may be broadly classified into low level languages and high level languages.

Low-level languages are described as machine-oriented languages. In these languages, programs are written using the memory and registers available on the computer. Since the architecture of computer differs from one machine to another, there is separate low level programming language for each type of computer. Machine language and assembly language are the different low level languages.

Machine language: We know that a computer can understand only special signals, which are represented by 1s and 0s. These two digits are called binary digits. The language, which uses binary digits, is called machine language. Writing a program in machine language is definitely very difficult. It is not possible to memorise a long string of 0s and 1s for every instruction.

Assembly language: Assembly language is an intermediate-level programming language. Assembly languages use mnemonics. Mnemonic is a symbolic name given to an operation. For example ADD for addition operation, SUB for subtraction operation, etc. It is easier to write computer programs in assembly language as compared to machine language. It is machine dependent and programmer requires knowledge of computer architecture.

High Level Languages (HLL): These are like English languages and are simpler to understand than the assembly language or machine language. High level language is not understandable to the computer. A computer program written in a high level language is to be converted into its equivalent machine language program. So these languages require a language translator (compilers or interpreters) for conversion. Examples of high-level programming languages are BASIC, C, C++, Java, etc.

Need for language processor

The programs consisting of instructions to the computer, written in assembly language or high level language are not understood by the computer. We need language processors to convert such programs into low level language, as computer can only understand machine language. Language processors are the system programs that translate programs written in high level language or assembly language into its equivalent machine language.

Types of language processors

- **Assembler:** Assembly languages require a translator known as assembler for translating the program code written in assembly language to machine language. Because computer can interpret only the machine code instruction, the program can be executed only after translating. An assembler is highly machine dependent.
- **Interpreter:** Interpreter is another kind of language processor that converts a HLL program into machine language line by line. If there is an error in one line, it reports and the execution of the program is terminated. It will continue the translation only after correcting the error. BASIC is an interpreted language.
- **Compiler:** Compiler is also a language processor that translates a program written in high level language into machine language. It scans the entire program in a single run. If there is any error in the program, the compiler provides a list of error messages along with the line number at the end of the compilation. If there are no syntax errors, the compiler will generate an object file. Translation using compiler is called compilation. After translation compilers are not required in memory to run the program. The programming languages that have a compiler are C, C++, Pascal, etc.

Figure 3.14 shows process involved in the translation of assembly language and high level language programs into machine language programs

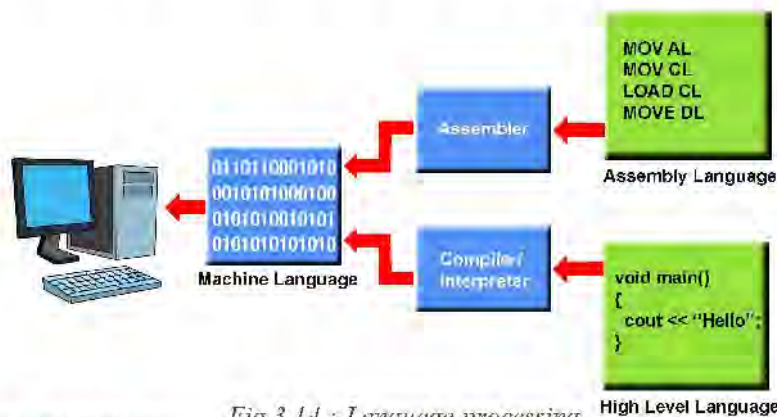


Fig.3.14 : Language processing

c. Utility software

Utility software is a set of programs which help users in system maintenance tasks and in performing tasks of routine nature. Some of the utility programs with their functions are listed below:

- **Compression tools:** Large files can be compressed so that they take less storage area. These compressed files can be decompressed into its original form when needed. Compression of files is known as zipping and decompression is called unzipping. WinZip, WinRAR, etc. are examples.

- **Disk defragmenter:** Disk defragmenter is a program that rearranges files on a computer hard disk. The files are arranged in such a way that they are no longer fragmented. This enables the computer to work faster and more efficiently.
- **Backup software:** Backup means duplicating the disk information so that in an event of disk failure or in an event of accidental deletion, this backup may be used. Backup utility programs facilitates the backing up of disk.
- **Antivirus software:** A computer virus is a program that causes abnormality in the functioning of a computer. Antivirus software is a utility program that scans the computer system for viruses and removes them. As new viruses are released frequently, we have to make sure that latest antivirus versions are installed on the computer. Most of the antivirus programs provide an auto-update feature which enables the user to download profiles of new viruses so as to identify and inactivate them. Norton Antivirus, Kaspersky, etc. are examples of antivirus programs.

3.5.2 Application software

Software developed for specific application is called application software. It includes general purpose software packages and specific purpose software. GIMP, Payroll System, Air line reservation System, Tally, etc. are examples of application software.

a. General purpose software packages

General purpose software are used to perform tasks in a particular application area. Such software is developed keeping in mind the various requirements of its users. They provide a vast number of features for its users. General purpose software is classified as word processors, spreadsheet software, presentation software, database software and multimedia software.

- **Word processing software:** Word Processing software is designed for creating and modifying documents. It helps to create, edit, format and print textual matters easily. Formatting features include different font settings, paragraph settings, bullets and numbering, alignments and more. In addition to this it can check spelling and grammar in the document, insertion of pictures, charts and tables. We can specify headers and footers for every page in the document. The most popular examples of this type of software are MS Word, Open Office Writer, Apple iWork Pages, etc.
- **Spreadsheet software:** Spreadsheet software allows users to perform calculations using spreadsheets. They simulate paper worksheets by displaying multiple cells that make up a grid. It also allows us to insert drawing objects in the worksheet and create different types of charts for graphical representation

of numerical data. Microsoft Excel, Open Office Calc, Lotus 1-2-3 and Apple iWork Numbers are some examples of spreadsheet software.

- **Presentation software:** The software that is used to display information in the form of a slide show is known as presentation software. Presentation software allows preparing slides containing pictures, text, animation, video and sound effects. Microsoft PowerPoint, Apple iWork Keynote and Open Office Impress are examples for presentation software.
- **Database software:** Database is an organised collection of data arranged in tabular form. Database Management System (DBMS) consists of a collection of interrelated data and a set of programs to access those data. The primary goal of a DBMS is to provide an environment that is both convenient and efficient to use in retrieving and storing database information. They provide privacy and security to data and enforce standards for data. Examples of DBMS software are Microsoft Access, Oracle, Postgres SQL, My SQL, etc.
- **Multimedia software:** Multimedia is the integration of multiple forms of media. This includes text, graphics, audio, video, etc. Multimedia software can process information in a number of media formats. It is capable of playing media files. Some multimedia software allows users to create and edit audio and video files. Audio converters, audio players and video editing software are some forms of multimedia software. Examples are VLC Player, Adobe Flash, Real Player, Media Player, etc.

b. Specific purpose software

Specific purpose software is a highly specialised software designed to handle particular tasks. These are tailor-made software to satisfy the needs of an organisation or institution. It is also known as customised software. Since custom software is developed for a single customer, it can accommodate that customer's particular preferences and expectations.

Some examples of specific purpose application software are listed in Table 3.7.

Application Software	Purpose
Payroll System	Payroll system maintains the details of employees of an organisation and keeps track of their salary details.
Inventory Management System	It is used for tracking inventory levels, orders, sales and deliveries in a business firm.
Human Resource Management System	It is used for managing human resource in an organisation.

Table 3.7 : Examples of application software

**Let us do**

- Discuss the classification of software.
- Compare and contrast the features of Linux and Windows operating systems with the help of your teacher and prepare short notes (Lab Demonstration). Discuss the role of utility software.
- Write short notes on the following:
 - Language processors
 - General purpose software packages

Check yourself

1. Define operating system.
2. Give two examples for OS.
3. A program in execution is called _____.
4. Mention any two functions of OS
5. Name the software that translates assembly language program into machine language program.
6. Name the two different language processors which translate high level language programs into machine language programs.
7. Differentiate between compiler and interpreter.
8. DBMS stands for _____.
9. Give two examples for customized software.
10. Duplicating disk information is called _____.

3.5.3 Free and open source software

Free and open source software gives the user the freedom to use, copy, distribute, examine, change and improve the software. Nowadays free and open source software is widely used throughout the world because of adaptable functionality, less overall costs, vendor independency, adherence to open standards, interoperability and security.

The Free Software Foundation (FSF) defines the four freedoms for free and open source software:

Freedom 0 : The freedom to run program for any purpose.

Freedom 1 : The freedom to study how the program works and adapt it to your needs. Access to source code should be provided.

Freedom 2 : The freedom to distribute copies of the software.

Freedom 3 : The freedom to improve the program and release your improvements to the public, so that the whole community benefits.

The following are some of the examples of free and open source software:

GNU/Linux: GNU/Linux is a computer operating system assembled under the model of free and open source software development and distribution. It was organised in the GNU project introduced in 1983 by Richard Stallman in the FSF.

GIMP: It stands for GNU Image Manipulation Program. It is an image editing software. It can be used for retouching photographs, creating and editing images. It supports graphic files of different formats and allows converting from one format to another.

Mozilla Firefox: It is one of the most popular web browsers created by the Mozilla Corporation. It provides added security features for safe browsing.

OpenOffice.org: It is a complete office suite that contains word processor (Writer) to prepare and format documents, spreadsheets (Calc) and presentations (Impress). It works on both Linux and Windows platforms.

3.5.4 Freeware and Shareware

Freeware refers to copyrighted computer software which is made available for use, free of charge, for an unlimited period.

The term shareware refers to commercial software that is distributed on a trial basis. It is distributed without payment and with limited functionality. Shareware is commonly offered in a downloadable format on the Internet. The distribution of this kind of software aims at giving users a chance to analyse the software before purchasing it. Some shareware works for a limited period of time only. Table 3.8 highlights a comparison between freeware and shareware:

Freeware	Shareware
<ul style="list-style-type: none"> Freeware refers to software that anyone can download from the Internet and use for free. All the features are free. Freeware programs can be distributed free of cost. 	<ul style="list-style-type: none"> Shareware gives users a chance to try the software before buying it. All features are not available. To use all the features of the software, user has to purchase it. Shareware may or may not be distributed freely. In many cases, author's permission is needed to distribute the shareware.

Table 3.8 : Comparison of Freeware and Shareware

3.5.5 Proprietary software

Proprietary software is a computer program that is an exclusive property of its developer or publisher and cannot be copied or distributed without licensing agreements. It is sold without any access to source code and is therefore cannot be changed for improved by the user. Some examples of proprietary software are Microsoft Windows operating system, MS Office, Mac OS, etc.

3.6 Humanware or Liveware

Humanware or liveware refers to humans who use computer. It was used in computer industry as early as 1966 to refer to computer users, often in humorous contexts by analogy with software and hardware. It refers to programmers, systems analysts, operating staff and other personnel working in a computer system. Table 3.9 shows various categories of humanware and their job description.

Humanware	Job Description
System Administrators	Upkeep, configuration and reliable operation of computer systems; especially multi-user computers such as servers.
System Managers	Ensure optimal level of customer services and maintain expertise in all business unit systems and develop professional relationships with all vendors and contractors.
System Analysts	Design new IT solutions to improve business efficiency and productivity.
Database Administrators	Create, monitor, analyse and implement database solutions.
Computer Engineers	Design either the hardware or software of a computer system.
Computer Programmers	Write the code that computers read in order to operate properly.
Computer Operators	Oversee the running of computer systems, ensuring that the machines are running, physically secured and free of any bugs.

Table 3.9 : Categories of humanware with job description

Check yourself



1. An example of free and open source software is _____.
2. The software that give users a chance to try it before buying is _____.
3. What do you mean by free and open source software?
4. Give an example for proprietary software.
5. Give two examples of humanware.



Let us sum up

Data processing is a series of activities by which data is converted into information. The limitations of manual data processing are overcome by electronic data processing and computer is the best electronic data processing machine. A computer has five functional units such as input unit, storage unit, arithmetic and logic unit, control unit and output unit. This chapter provided a general overall introduction to computer organisation. Input and output devices, e-waste and its disposal methods and the importance of green computing were introduced. The classification of software and the need of operating system in a computer with its major functions were discussed. Following this, the categories of computer languages were presented. The concepts of open source, freeware, shareware, free software and proprietary software were also discussed in detail. The chapter concluded outlining the concept of humanware.



Learning outcomes

After the completion of this chapter the learner will be able to

- distinguish between data and information.
- identify various stages in data processing.
- explain basic organisation of computer system.
- recognise the different types of input and output devices.
- distinguish between system software and application software.
- identify the importance of e-Waste disposal.
- identify the importance of green computing concept.
- classify the different types of software.
- recognise the functions of operating system.
- use word processor, electronic spreadsheets and presentation software.
- classify the different types of computer languages.
- list the different types of utility software.
- promote open source software.
- explain the term humanware or liveware.

Sample questions**Very short answer type**

1. What is data?
2. Processed data is known as _____.
3. What are the components of a digital computer?
4. Write the main functions of central processing unit.
5. What are the different types of main memory?
6. What is the advantage of EEPROM over EPROM?
7. When do we use ROM?
8. What is an input device? List few commonly used input devices.
9. What do you mean by an output device? List few commonly used output devices.
10. What is a storage device? List few commonly used storage devices.
11. What is the role of ALU?
12. What is a control unit?
13. What are registers? Write and explain any two of them.
14. Differentiate hard copy and soft copy.
15. What is e-Waste?
16. What is operating system?
17. What is a language processor?
18. Mention the categories of computer languages.
19. What is disk defragmenter?
20. Why is OS considered as a 'resource manager'?
21. What is proprietary software?
24. What do you mean by open source software?

Short answer type

1. Distinguish between data and information.
2. The application form for Plus One admission contains your personal details and your choice of groups and schools.
 - (a) Identify the data and information in the admission process.
 - (b) Explain how the information helps the applicants and school authorities.
 - (c) Write down the activities involved in the processing of the data.

3. Briefly explain any three input devices.
4. Compare CRT with LED monitor
5. Differentiate between RAM and ROM
6. List and explain e-waste disposal methods.
7. Enumerate the steps that can be taken for the implementation of green computing philosophy.
8. What do you mean by customised software? Give examples.
9. Distinguish between low level and high level languages.
10. Differentiate compiler and interpreter.
11. Describe the use of electronic spreadsheets.
12. What is utility software? Give two examples.
13. Categorise the software given below into operating system, application packages and utility programs. Linux, Tally, WinZip, MS-Word, Windows, MS-Excel
14. Differentiate between freeware and shareware.
15. What are the four freedoms which make up free and open source software?
16. What do you mean by human-ware? Give any two examples.

Long answer type

1. Taking the case of a real life example, briefly describe the activities involved in each stage of data processing.
2. With the help of a block diagram, explain the functional units of a computer.
3. Describe in detail the various units of the Central Processing Unit.
4. Briefly explain various types of memory.
5. Explain classification of printers.
6. "e-Waste is hazardous to our health and environment." Justify the statement. List and explain the methods commonly used for e-Waste disposal.
7. Define the term green computing. List and explain the approaches that you can adopt to promote green computing concepts at all possible levels.
8. List and explain various categories of software.
9. Describe the use of various utility software.
10. Define the term 'operating system'. List and explain the major functions of operating system.
11. List and explain general purpose application software with examples.
12. Compare freeware and shareware.

Key concepts

- **Problem solving using computers**
- **Approaches in problem solving**
 - Top down design
 - Bottom up design
- **Phases in programming**
 - Problem identification
 - Algorithms and Flowcharts
 - Coding the program
 - Translation
 - Debugging
 - Execution and testing
 - Documentation
- **Performance evaluation of algorithms**

Principles of Programming and Problem Solving

We have learnt the concept of data processing and the role of computers in data processing. We have also discussed the computer as a system with components such as hardware, software and users. We had a detailed discussion on these components in the previous chapter. Let us recall the definition of software. In its simplest form, we can say that software means a collection of programs to solve problems using computers. As we know, a computer cannot do anything on its own. It must be instructed to perform the desired job. Hence it is necessary to specify a sequence of instructions that the computer must perform to solve a problem. Such a sequence of instructions written in a language that is understood by a computer is called a “computer program”. Writing a computer program is a challenging task. However, we can attempt it by procuring the concepts of problem solving techniques and different stages of programming.

4.1 Problem solving using computers

A computer can solve problems only when we give instructions to it. If it understands the tasks contained in the instructions, it will work accordingly. An instruction is an action oriented statement. It tells the computer what operation it should perform. A computer can execute (carry out the task contained in) an instruction only if the task is specified precisely and accurately. As we learned in the previous chapter, there are programmers who develop sequence of instructions for solving problems. Once the program is developed and stored permanently in a computer, we can ask the computer to execute it as and when required.

We should be cautious about the clarity of the logic of the solution and the format of instructions while designing a program, because computer does not possess common sense or intuition. As human beings, we use judgments based on experience, often on subjective and emotional considerations. Such value oriented judgments often depend on what is called "common sense". As opposed to this, a computer exhibits no emotion and has no common sense. That is why we say that computer has no intelligence of its own.

In a way, computer may be viewed as an 'obedient servant'. Being obedient without exercising 'common sense' can be very annoying and unproductive. Take the instance of a master who sent his obedient servant to a post office with the instruction "Go to the post office and buy ten 5 rupees stamps". The servant goes to the post office with the money and does not return even after a long time. The master gets worried and goes in search of him to the post office and finds the servant standing there with the stamps in his hand. When the angry master asks the servant for an explanation, the servant replies that he was ordered to buy ten 5 rupees stamps but not to return with them!

4.2 Approaches in problem solving

A problem may be solved in different ways. Even the approach may be different. In our life, we may seek medical treatment for some diseases. We can consult an allopathic, ayurvedic or homoeopathic doctor. Each of their approaches may be different, though all of them are solving the same problem. Similarly in problem solving also different approaches are followed. Let us discuss the two popular designing styles of problem solving – Top down design and Bottom up design.

4.2.1 Top down design

Look at Figure 4.1. If you are asked to draw this picture, how will you proceed? It may be as follows:

1. Draw the outline of the house.
2. Draw the chimney
3. Draw the door
4. Draw the windows

The procedure described above may be summarised as follows:

While drawing the door in Step 3, the procedure may be as follows:

- 3.1 Outline of the door
- 3.2 Shading
- 3.3 Handle

Similarly the windows may be drawn as follows:

- 4.1 Outline of the window
- 4.2 Shading
- 4.3 Horizontal and Vertical lines

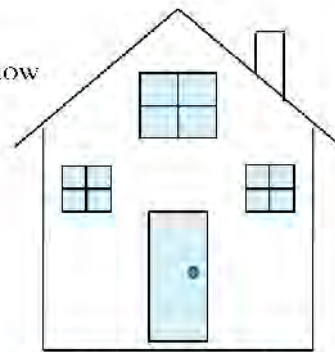


Fig. 4.1 : Lay-out of a House

The whole problem (here drawing the picture) is broken down into smaller tasks. Thus four tasks are identified to solve the problem. Some of these tasks (here steps 3 and 4 for drawing the door and windows) are further subdivided. Thus any complex problem can be solved by breaking it down into different tasks and solving each task by performing simpler activities. This concept is known as **top down design** in problem solving.

It is one of the programming approaches that has been proven the most productive. As shown in Figure 4.2, top down design is the process of breaking the overall procedure or task into component parts (modules) and then subdividing each component module until the lowest level of detail is reached. It is also called top down decomposition since we start "at the top" with a general problem and design specific solutions to its sub problems. In order to obtain an effective solution for the main problem, it is desirable that the sub problems (sub programs) should be independent of each other. So, each sub problem can be solved and tested independently.

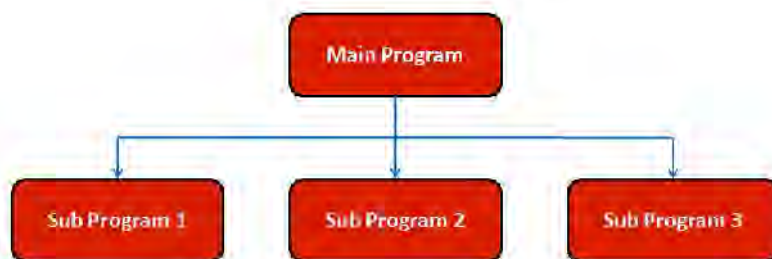


Fig. 4.2 : Decomposition of a problem

The following are the advantages of problem solving by decomposition:

- Breaking the problem into parts helps us to clarify what is to be done in each part.
- At each step of refinement, the new parts become less complicated and therefore, easier to figure out.
- Parts of the solution may turn out to be reusable.
- Breaking the problem into parts allows more than one person to work for the solution.

4.2.2 Bottom up design

Consider the case of constructing a house. We do not follow the top down design, but the bottom up design. The foundation will be the first task and roofing will be the last task. Breaking down of tasks is carried out here too. It is true that some tasks can be carried out only after the completion of some other tasks. However roofing which is the main task will be carried out only after the completion of bottom level tasks.

Similarly in programming, once the overall procedure or task is broken down into component parts (modules) and each component module is further sub divided until the lowest level of detail has been reached, we start solving from the lowest module

onwards. The solution for the main module will be developed only after designing specific solutions to its sub modules. This style of approach is known as **bottom-up design** for problem solving. Here again, it is desirable that the sub problems (subprograms) should be independent of each other.



Let us do

Youth festivals are conducted every year in our schools. Usually the duties and responsibilities are decomposed. Discuss how the tasks are divided and executed to organise the youth festival successfully.

4.3 Phases in programming

As we have seen, problem solving using computer is a challenging task. A systematic approach is essential for this. The programs required can be developed only by going through different stages. Though we have in-born problem solving skills, it can be applied effectively only by proper thinking, planning and developing the logical reasoning to solve the problem. We can achieve this by proceeding through the following stages, in succession:

1. Problem identification
2. Preparing algorithms and flowcharts
3. Coding the program using programming language
4. Translation
5. Debugging
6. Execution and Testing
7. Documentation

Figure 4.3 shows the order of performing the tasks in various stages of programming. Note that the debugging stage is associated with both translation and execution. The activities involved in the seven stages mentioned above are detailed in the following sections.

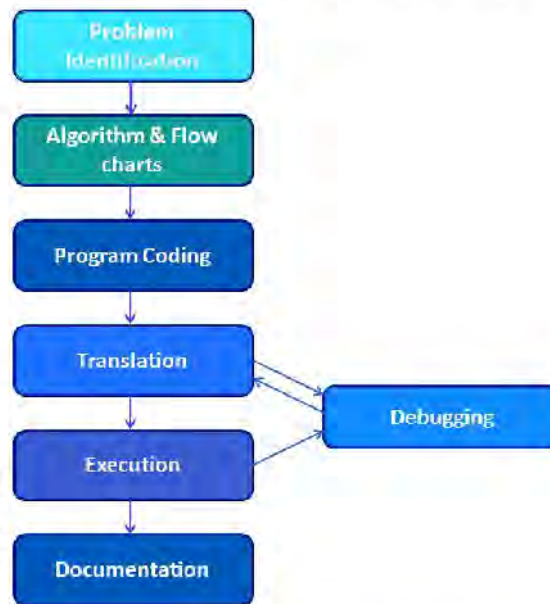


Fig. 4.3 : Phases of Programming

4.3.1 Problem identification

Let us discuss a real life situation; suppose you are suffering from a stomach ache. As you know this problem can be solved by a doctor. Your doctor may ask you some questions regarding the duration of pain, previous occurrence, your diet etc., and examine some parts of your body using the stethoscope, X-ray or scan. All these are a

part of the problem study. After these procedures, your doctor may be able to identify the problem and state it using some medical term. Now the second stage begins with the derivation of some steps for solution known as prescriptions.

It is clear that before deriving the steps for solution, the problem must be analysed. During this phase you will be able to identify the data involved in processing, its type and quantity, formula to be used, activities involved, and the output to be obtained. Once you have studied the problem clearly, and are convinced about the sequence of tasks required for the solution, you can go to the next phase. This is the challenging phase as it exploits the efficiency of the programmer (problem solver).

4.3.2 Algorithms and Flowcharts

Once the problem is identified, it is necessary to develop a precise step-by-step procedure to solve the problem. This procedure is not new or confined to computers. It has been in use for a very long time, and in almost all walks of life. One such procedure taken from real life is described below. It is a cooking recipe of an omlette taken from a magazine.

Ingredients

Eggs - 2 Nos, Onion - 1 (small sized, chopped); Green chili - 2 (finely chopped); Oil - 2 tea spoon, Salt - a pinch.

Method

- Step 1 : Break the eggs and pour the contents in a vessel and stir.
- Step 2 : Mix chopped onion, green chilies and salt with the stirred egg.
- Step 3 : Place a pan on the stove and light the stove.
- Step 4 : Pour the oil in the pan and wait till it gets heated.
- Step 5 : Pour the mixture prepared in step 2 into the pan and wait till the side is fried.
- Step 6 : Turn over to get the other side fried well.
- Step 7 : Take it out after some seconds.

Result

An omlette is ready to be served with pepper powder.

The recipe given above has the following properties:

1. It begins with a list of ingredients required for making the omlette. These may be called the inputs.
2. A sequence of instructions is given to process the inputs.



3. As a result of carrying out the instructions, some outputs (here, omlette) are obtained.

The instructions given to process the inputs are, however, not precise. They are ambiguous. For example, the interpretation of "till the side is fried" in step 5 and "fried well" in step 6 can vary from person to person. Due to such imprecise instructions, different persons following the same recipe with the same inputs can produce omlettes which differ in size, shape and taste.

The above ambiguities should be avoided while writing steps to solve the problems using the computer.

a. Algorithm

Mathematicians trace the origin of the word algorithm to a famous Arab mathematician, Abu Jafar Mohammed Ibn Musaa Al-Khowarizmi. The word 'algorithm' is derived from the last part of his name Al-Khowarizmi. In computer terminology an **algorithm** may be defined as a finite sequence of instructions to solve a problem. It is a step-by-step procedure to solve a problem, where each step represents a specific task to be carried out. However, in order to qualify an algorithm, a sequence of instructions must possess the following characteristics:



*Fig. 4.4 : Abu Jafar Mohammed
Ibn Musaa Al-Khowarizmi
(780 - 850)*

- (i) It should begin with instruction(s) to accept inputs. These inputs are processed by subsequent instructions. Sometimes, the data to be processed will be given along with the problem. In such situations, there will be no input instruction at the beginning of the algorithm.
- (ii) Use variables to refer the data, where variables are user-defined words consisting of alphabets and numerals that are similar to those used in mathematics. Variables must be used for inputting data and assigning values or results.
- (iii) Each and every instruction should be precise and unambiguous. In other words, the instructions must not be vague. It must be possible to carry them out. For example, the instruction "Catch the day" is precise, but cannot be carried out.
- (iv) Each instruction must be sufficiently basic such that it can, in principle, be carried out in finite time by a person with paper and pencil.
- (v) The total time to carry out all the steps in the algorithm must be finite. As algorithm may contain instructions to repetitively carry out a group of instructions, this requirement implies that the number of repetitions must be finite.
- (vi) After performing the instructions given in the algorithm, the desired results (outputs) must be obtained.

To gain insight into algorithms, let us consider a simple example. We have to find the sum and average of any three given numbers. Let us write the procedure for solving this problem. It is given below:

- Step 1: Input three numbers.
- Step 2: Add these numbers to get the sum
- Step 3: Divide the sum by 3 to get the average
- Step 4: Print sum and average

Though the procedure is correct, while preparing an algorithm, we have to follow any of the standard formats. Let us see how the procedure listed above can be written in an algorithm style.

Example 4.1: Algorithm to find the sum and average of three numbers

Let A, B, C be variables for the input numbers; and S, Avg be variables for sum and average.

- Step 1: Start
- Step 2: Input A, B, C
- Step 3: $S = A + B + C$
- Step 4: $Avg = S / 3$
- Step 5: Print S, Avg
- Step 6: Stop

The above set of instructions qualifies as an algorithm for the following reasons:

- It has input (The variables A, B and C are used to hold the input data).
- The processing steps are precisely specified (Using proper operators in Steps 3 and 4) and can be carried out by a person using pen and paper.
- Each instruction is basic (Input, Print, Add, Divide) and meaningful.
- It produces two outputs such as sum (S) and average (Avg).
- The beginning and termination points are specified using Start and Stop.

Types of instructions

As we know, a computer can perform only limited types of operations. So we can use only that many instructions to solve problems. Before developing more algorithms, let us identify the types of instructions constituting the algorithm.

- Computer can accept data that we input. So, we can use input instructions. The words **Input**, **Accept** or **Read** may be used for this purpose.
- Computer gives the results as output. So we can use output instructions. The words **Print**, **Display** or **Write** may be used for this purpose.

- Data can directly be stored in a memory location or data may be copied from one location to another. Similarly, results of arithmetic operations on data can also be stored in memory locations. We use assignment (or storing) instruction for this, similar to that used in mathematics. Variables followed by the equal symbol (=) can be used for storing value, where variables refer to memory locations.
- A computer can compare data values (known as logical operation) and make decisions based on the result. Usually, the decision will be in the form of selecting or skipping a set of one or more statements or executing a set of instructions repeatedly.

b. Flowcharts

An idea expressed in picture or diagram is preferred to text form by people. In certain situations, algorithm may be difficult to follow, as it may contain complex tasks and repetitions of steps. Hence, it will be better if it could be expressed in pictorial form. The pictorial representation of an algorithm with specific symbols for instructions and arrows showing the sequence of operations is known as **flowchart**. It is primarily used as an aid in formulating and understanding algorithms. Flowcharts commonly use some basic geometric shapes to denote different types of instructions. The actual instructions are written within these boxes using clear and concise statements. These boxes are connected by solid lines with arrow marks to indicate the flow of operation; that is, the exact sequence in which the instructions are to be executed.

Normally, an algorithm is converted into a flowchart and then the instructions are expressed in some programming language. The main advantage of this two-step approach in program writing is that while drawing a flowchart one is not concerned with the details of the elements of programming language. Hence he/she can fully concentrate on the logic (step-by-step method) of the procedure. Moreover, since a flowchart shows the flow of operations in pictorial form, any error in the logic of the procedure can be detected more easily than in a program. The algorithm and flow chart are always a reference to the programmer. Once these are ready and found correct as far as the logic of the solution is concerned, the programmer can concentrate on coding the operations following the constructs of programming language. This will normally ensure an error-free program.

Flowchart symbols

The communication of program logic through flowcharts is made easier through the use of symbols that have standardised meanings. We will only discuss a few symbols that are needed to indicate the necessary operations. These symbols are standardised by the American National Standards Institute (ANSI).

1. Terminal

As the name implies, it is used to indicate the beginning (START) and ending (STOP) in the program logic flow. It is the first symbol and the last symbol in the flowchart.

It has the shape of an ellipse. When it is used as START, an exit flow will be attached. But when it is used as a STOP symbol, an entry flow will be attached.



2. Input / Output

The parallelogram is used as the input/output symbol. It denotes the function of an input/output device in the program. All the input/output instructions are expressed using this symbol. It will be attached with one entry flow and one exit flow.



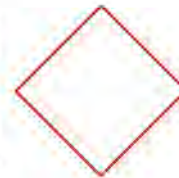
3. Process

A rectangle is used to represent the processing step. Arithmetic operations such as addition, subtraction, multiplication, division as well as assigning a value to a variable are expressed using this symbol. Assigning a value to a variable means moving data from one memory location to another (e.g. $a=b$) or moving the result from ALU to memory location (e.g. $a=b+5$) or even storing a value to a memory location (e.g. $a=2$). Process symbol also has one entry flow and one exit flow.



4. Decision

The rhombus is used as decision symbol and is used to indicate a point at which a decision has to be made. A branch to one of two or more alternative points is possible here. All the possible exit paths will be specified, but only one of these will be selected based on the result of the decision. Usually this symbol has one entry flow and two exit flows - one towards the action based on the truth of the condition and the other towards the alternative action.



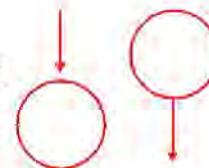
5. Flow lines

Flow lines with arrow heads are used to indicate the flow of operation, that is, the exact sequence in which the instructions are to be executed. The normal flow is from top to bottom and left to right. But in some cases, it can be from right to left and bottom to top. Good practice also suggests that flow lines should not cross each other and such intersections should be avoided wherever possible.



6. Connector

When a flowchart becomes bigger, the flow lines start criss-crossing at many places causing confusion and reducing comprehension of the flowchart. Moreover, when the flowchart becomes too long to fit



into a single page the use of flow lines becomes impossible. Whenever a flowchart becomes complex and the number and direction of flow lines is confusing or it spreads over more than one page, a pair of connector symbols can be used to join the flow lines that are broken. This symbol represents an "entry from", or an "exit to" another part of the flowchart. A connector symbol is represented by a circle and a letter or digit is placed within the circle to indicate the link. A pair of identically labelled connector symbols is commonly used to indicate a continuous flow. So two connectors with identical labels serve the same function as a long flow line. That is, in a pair of identically labelled connectors, one shows an exit to some other chart section and the other indicates an entry from another part of the chart.

Figure 4.5 shows that flowchart of the problem discussed in Example 4.1.

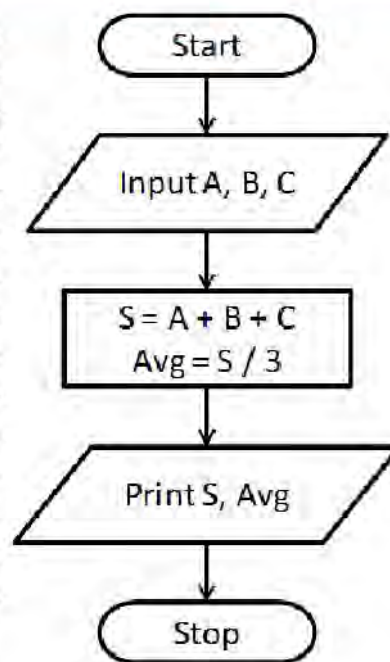


Fig. 4.5 : Flow chart for Sum and Average

The instruction given in each step in the algorithm is represented using the concerned symbol. Each symbol is labelled properly with the respective instruction. The flow of operations is clearly shown using the flow lines.

Advantages of flowcharts

Flowcharts are beneficial in many ways in program planning.

- **Better communication:** Since a flowchart is a pictorial representation of a program, it is easier for a programmer to explain the logic of the program to some other programmer through a flowchart rather than the program itself.
- **Effective analysis:** The whole program can be analysed effectively through the flowchart as it clearly specifies the flow of the steps constituting the program.
- **Effective synthesis:** If a problem is divided into different modules and the solution for each module is represented in flowcharts separately, they can finally be placed together to visualize the overall system design.
- **Efficient coding:** Once a flowchart is ready, programmers find it very easy to write the concerned program because the flowchart acts as a road map for them. It guides them to go from the starting point of the program to the final point ensuring that no steps are omitted.

Limitations of flowcharts

In spite of their many obvious advantages, flowcharts have some limitations:

- Flowcharts are very time consuming and laborious to draw with proper symbols and spacing, especially for large complex algorithms.
- Owing to the symbol-string nature of flowcharting, any change or modification in the logic of the algorithm usually requires a completely new flowchart.
- There are no standards determining the amount of detail that should be included in a flowchart.

Now let us develop algorithms and draw flowcharts for solving various problems.

Example 4.2: To find the area and perimeter of a rectangle

We know that this problem can be solved, if the length and breadth of the rectangle are given. The result can be obtained by using the following formula:

Perimeter = $2 (\text{Length} + \text{Breadth})$, Area = $\text{Length} \times \text{Breadth}$

Let L and B be variables for length and breadth; and P, A be variables for perimeter and area.

- Step 1: Start
 Step 2: Input L, B
 Step 3: $P = 2 * (L + B)$
 Step 4: $A = L * B$
 Step 5: Print P, A
 Step 6: Stop

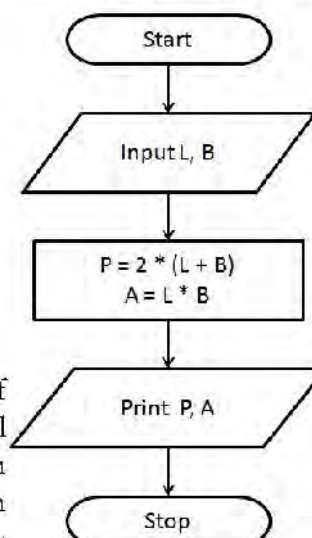


Fig. 4.6 : Flow chart for Area and Perimeter

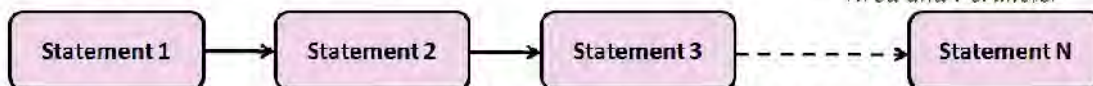


Fig. 4.7 : Sequential flow of control



Let us do

Develop an algorithm and draw the flow chart to input a time in seconds and convert it into the Hr: Min: Sec format. (For example, if 3700 is given as input, the output should be 1 Hr: 1 Min: 40 Sec).

Example 4.3: Find the height of the taller one among two students

Here, two numbers representing the height of two students are to be input. The larger number is to be identified as the result. We know that a comparison between these numbers is to be made for this. The algorithm is given below:

- Step 1: Start
- Step 2: Input H1, H2
- Step 3: If $H1 > H2$ Then
- Step 4: Print H1
- Step 5: Else
- Step 6: Print H2
- Step 7: End of If
- Step 8: Stop

The flowchart of this algorithm is shown in Figure 4.8. This algorithm uses the decision making aspect. In step 3, a condition is checked. Obviously the result may be True or False based on the values of variables H1 and H2. The decision is made on the basis of this result. If the result is True, step 4 will be selected for execution, otherwise step 6 will be executed. Here one of the two statements (either step 4 or step 6) is selected for execution based on the condition. A branching is done in step 3. That is, this algorithm uses the selection structure to solve the problem. As shown in Figure 4.9, the condition branches the flow to one of the two sets based on the result of condition.

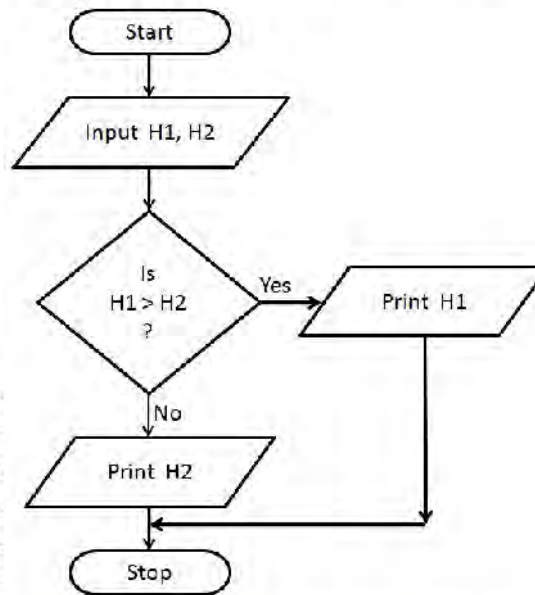


Fig. 4.8 : Flowchart to find larger value

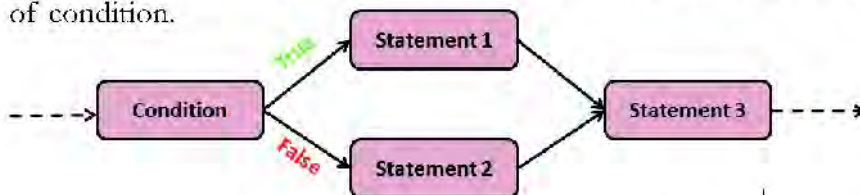


Fig. 4.9 : Selection structure

The working of selection construct is as shown in Figure 4.10. The flow of control comes to the condition; it will be evaluated to True or False. If the condition is True, the instructions given in the true block will be executed and false block will be skipped. But if the condition is False, the true block will be skipped and the false block will be executed. Now let us solve another problem.

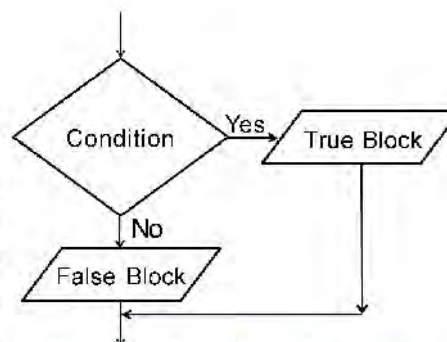


Fig. 4.10 : Flowchart of selection

Example 4.4: To input the scores obtained in 3 unit-tests and find the highest score

Here we have to input three numbers representing the scores and find the largest number among them. The algorithm is given below and flowchart is shown in Figure 4.11.

- Step 1: Start
 Step 2: Input M1, M2, M3
 Step 3: If $M1 > M2$ And $M1 > M3$ Then
 Step 4: Print M1
 Step 5: Else If $M2 > M3$ Then
 Step 6: Print M2
 Step 7: Else
 Step 8: Print M3
 Step 9: End of If
 Step 10: Stop

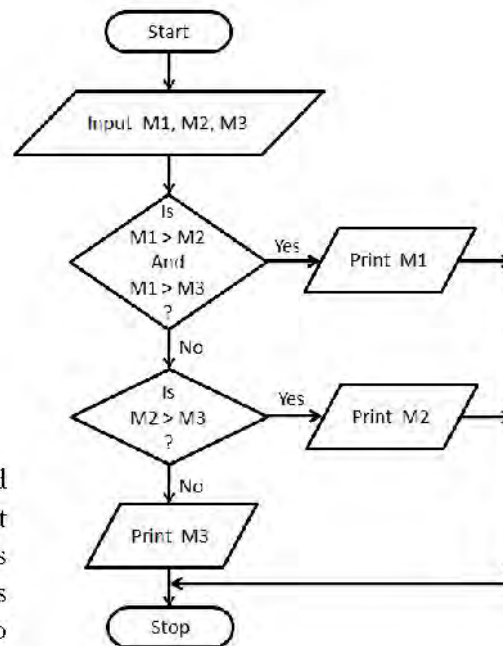


Fig. 4.11 : Flowchart to find the largest of three numbers



Let us do

1. Develop an algorithm and draw the flowchart to check whether a given number is even or odd.
2. Design an algorithm and flow chart to input a day number and display the name of the day. (For example, if 1 is the input, the output should be Sunday. If it is 2, the output should be Monday. If the number is other than 1 to 7, the output should be "Invalid data").
3. Based on the evaluation system for standard X, develop an algorithm to accept a score out of 100 and find the grade.

Now, consider a case in which some task is to be performed in a repeated fashion. Suppose we want to print the first 100 natural numbers. How do we do it? We know that the first number is 1. It should be printed. The next number is obtained by adding 1 to the first number. Again it should be printed. It is clear that the two tasks - printing a number and adding 1 to it - are to be executed repeatedly. The execution should be terminated when the last number is printed. Let us develop the algorithm for this.

Example 4.5: To print the numbers from 1 to 100

- Step 1: Start
 Step 2: $N = 1$
 Step 3: Print N
 Step 4: $N = N + 1$
 Step 5: If $N \leq 100$ Then Go To Step 3
 Step 7: Stop

In the algorithm given as Example 4.5, a condition is checked at step 5. If the condition is found true, the flow of control is transferred back to step 3. So the steps 3, 4 and 5 are executed repeatedly as long as the condition is true. We will say that a loop is formed here. Steps 3, 4 and 5 constitute a loop. The control comes out of the loop only when the condition becomes false. The flowchart of this algorithm is shown in Figure 4.12.

The above algorithm can be simplified as follows:

- Step 1: Start
 Step 2: $N = 1$
 Step 3: Repeat Steps 4 and 5 While ($N \leq 100$)
 Step 4: Print N
 Step 5: $N = N + 1$
 Step 6: Stop

Note that in step 3, the words "**Repeat**" and "**While**" are used to construct a loop. The statements (step numbers) that need repeated execution is specified with the word "**Repeat**" and the condition is given with "**While**". As the algorithm looks slightly different, the flow chart also differs slightly as in Figure 4.13. The execution style of a loop is shown in Figure 4.14.

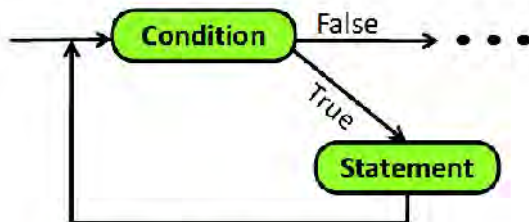


Fig. 4.14 : Looping construct

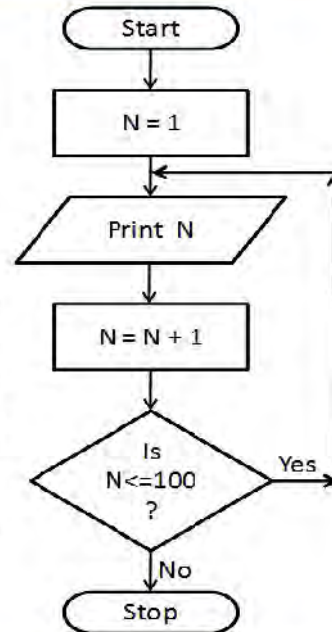


Fig. 4.12 : Flowchart to print numbers from 1 to 100

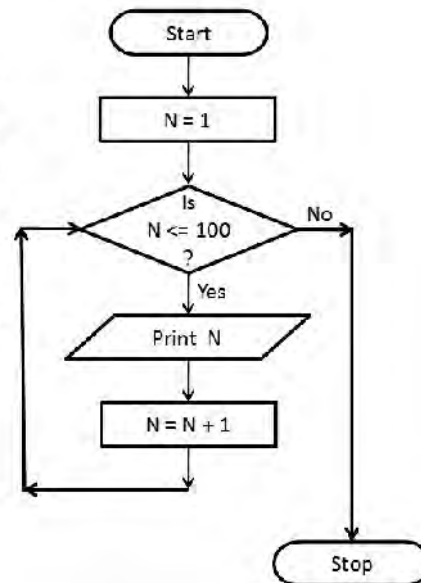


Fig. 4.13 : Flowchart to print numbers from 1 to 100

A loop has four elements. Obviously, one of them is the **condition**. We know that at least one variable will be used to put up a condition and let us call it loop control variable. Before the condition being checked, the loop control variable should get a value. It is possible through input or assignment. Such an instruction is called **initialisation instruction** for the loop. The third element, called **update instruction**, changes the value of the loop control variable. It is essential; otherwise the execution of the loop will never be terminated. The fourth element is the **loop body**, which is the set of instructions to be executed repeatedly. The flowchart shown in Figure 4.15 depicts the working of looping structure.

The initialisation instruction will be executed first and then the condition will be checked. If the condition is true, the body of the loop will be executed followed by the update instruction. After the execution of the update instruction, the condition will be checked again. This process will be continued until the condition becomes false. The loop that checks the condition before executing the body is called entry-controlled loop. There is another style of looping construct. In this case, the condition will be checked only after the execution of loop-body and update instruction. Such a loop is called exit-controlled loop.

Example 4.6: To print the sum of the first N natural numbers

Here we have to input the value of N. The sum of numbers from 1 to the input number N is to be found out. Let S be the variable to store the sum. Figure 4.16 shows the flowchart of this algorithm

- Step 1: Start
- Step 2: Input N
- Step 3: $A = 1, S = 0$
- Step 4: Repeat Steps 5 and 6 While ($A \leq N$)
- Step 5: $S = S + A$
- Step 6: $A = A + 1$
- Step 7: Print S
- Step 8: Stop

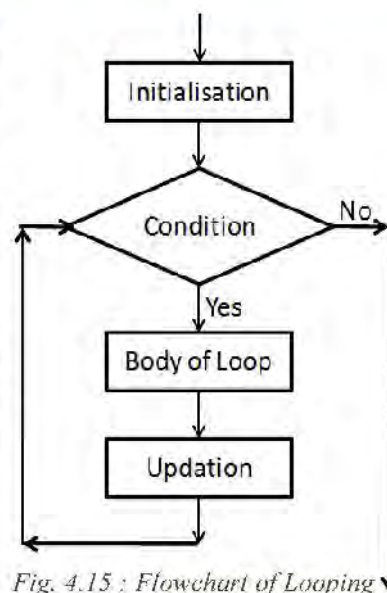


Fig. 4.15 : Flowchart of Looping

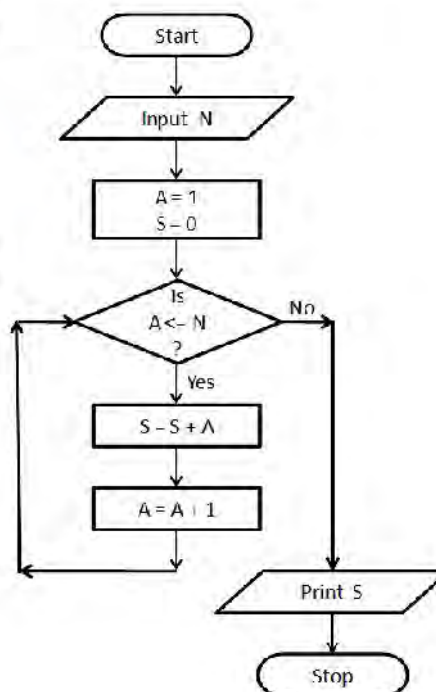


Fig. 4.16 : Flowchart for the sum of first N natural numbers

This algorithm uses an entry-controlled loop. In the next example we can see an algorithm that uses exit-controlled loop for problem solving.

Example 4.7: To print the first 10 multiples of a given number

- Step 1: Start
 Step 2: Input N
 Step 3: $A = 1$
 Step 4: $M = A \times N$
 Step 5: Print M
 Step 6: $A = A + 1$
 Step 7: Repeat Steps 4 to 6 While ($A \leq 10$)
 Step 8: Stop

This algorithm and the corresponding flowchart shown in Figure 4.17 contain a loop in which the condition is checked only after executing the body. Table 4.1 shows comparison between entry controlled loops and exit controlled loops.

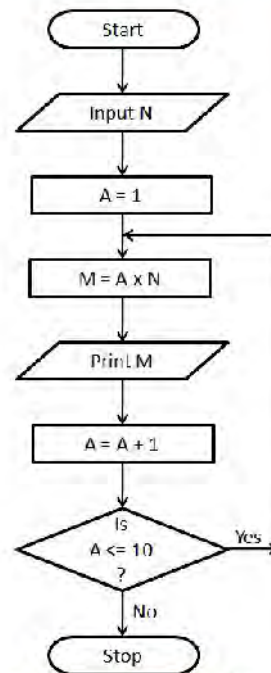


Fig. 4.17 : Flowchart for the first 10 multiples of a number

Entry Controlled Loop	Exit Controlled Loop
<ul style="list-style-type: none"> Condition is checked before the execution of the body Body may never be executed. Suitable when skipping of the body from being executed is required 	<ul style="list-style-type: none"> Condition is checked after the execution of the body Body will surely be executed at least once. Suitable when normal execution of the body is to be ensured.

Table 4.1 : Comparison of Loops

Let us practice with more algorithms and flowcharts for solving the problems that are given as learning activities.



Develop an algorithm and draw the flowcharts for the following problems:

Let us do

- To print all even numbers below 100 in the descending order.
- To find the sum of odd numbers between 100 and 200.
- To print the multiplication table of a given number.
- To find the factorial of a number.
- To input a number and check whether it is prime or not.

4.3.3 Coding the program

Once we have developed the skill to design algorithms and flowcharts, the next step in programming is to express the instructions in a more precise and concise notation. That is, the instructions are to be expressed in a programming language. The process of writing such program instructions to solve a problem is called **coding**. Text editor programs are available to write the code in computer.



A language is a system of communication. We communicate our ideas and emotions to one another through natural languages such as English, Malayalam, etc. Similarly, a computer language is used to communicate between user and computer. A human being who writes a computer program is to be familiar with a language that is understandable to the computer also. We have already seen that computer knows only the binary language which is very difficult for human beings to understand and use.

As we saw in Chapter 3, we can use a human friendly language, known as High Level Language (HLL) that looks similar to English. Again there is a facility of using language processors to convert or translate the program written in HLL into machine language. The program written in any HLL is known as **source code**.

Hence, to be a programmer we have to be well-versed in any HLL such as BASIC, COBOL, Pascal, C++ etc. to express the instructions in a program. Each language has its own character set, vocabulary, grammar (we call it syntax) to write programs. Once the program is written using a language, it should be saved in a file (called source file), and then proceed to the next phase of programming.

4.3.4 Translation

While selecting a language for developing source code, certain criteria such as volume of data, complexity in process, usage of files, etc. are to be considered. Once a language is selected and the source code is prepared, it should be translated using the concerned language processor. **Translation** is the process of converting a program written in high level language into its equivalent version in machine language. The compiler or interpreter is used for this purpose. During this step, the syntax errors of the program will be displayed. These errors are to be corrected by opening the file that contains the source code. The source code is again given for compilation (translation). This process will be continued till we get a message such as "No errors or warnings" or "Successful compilation". Now we have a program fully constituted by machine language instructions. This version of the source code is known as **object code** and it will be usually stored in a file by the compiler itself.



Fig. 4.18 : Translation process

Once the object code is obtained it should be present in the system as long as you want the program to be used.

4.3.5 Debugging

Debugging is the stage where programming errors are discovered and corrected. As long as computers are programmed by human beings, the programs will be subject to errors. Programming errors are known as 'bugs' and the process of detecting and correcting these errors is called **debugging**. In general there are two types of errors that occur in a program – syntax errors and logical errors. **Syntax errors** result when the rules or syntax of the programming language are not followed. Such program errors typically involve incorrect punctuation, incorrect word sequence, undefined term, or illegal use of terms or constructs. Almost all language processors detect syntax errors when the program is given for translation. They print error messages that include the line number of the statement having errors and give hints about the nature of the error. In the case of interpreters, the syntax errors will be detected and displayed during execution. The programmer's efficiency in using the language decides the time and effort for the debugging process. The object program will be generated only if all the syntax errors are rectified.

The second type of error, named **logical error**, is due to improper planning of the program's logic. The language processor successfully translates the source code into machine code if there are no syntax errors. During the execution of the program, computer actually follows the program instructions and gives the output as per the instructions. But the output may not be correct. This is known as logical error. When a logical error occurs, all you know is that the computer is not giving the correct output. The computers do not tell us what is wrong. It should be identified by the programmer or user. In order to determine whether or not there is a logical error, the program must be tested. So, let us move on to the next stage of programming.

4.3.6 Execution and testing

As we have seen in the previous section, the program is said to be error-free only when logical errors are also rectified. Hence when the compiled version of the program is formed, it should be executed for testing. The purpose of testing is to determine whether the results are correct. The testing procedure involves running the program to process the test data that will produce 'known results'. That is, the operations involved in the program should be done manually and the output thus obtained should be compared with the one given by the computer. The accuracy of the program logic can be determined by this testing. While selecting the test data, we should ensure that all aspects of the program logic will be tested. Hence the selection of proper test data is important in program testing.



Till now, we have discussed incorrect outputs due to incorrect logic. But there is a chance of another type of error, which will interrupt the program execution. This may be due to the inappropriate data that is encountered in an operation. For example consider an instruction $A = B/C$. This statement causes interruption in execution if the value of C happens to be zero. In such a situation, the error messages may be displayed by the error-handling function of the language. These errors are known as **Run-time error**. These errors can be rectified by providing instructions for checking the validity of the data before it gets processed by the subsequent instructions in the program.

4.3.7 Documentation

A computerised system cannot be considered to be complete until it is properly documented. In fact documentation is an on-going process that starts in the problem-study phase of the system and continues till its implementation and operation. We can write comments in the source code as part of documentation. It is known as **internal documentation**. It helps the debugging process as well as program modification at a later stage. The logic that we applied in the program may not be remembered when we go through our own program at a later stage. Besides, the program written by one person may need to be modified by some other person in future. If the program is documented, it will help to understand the logic we applied, the reason why a particular statement has been used and so on. However, the documentation part of the program will not be considered by the language processor when you give the program for translation.

Writing comments in programs is only a part of documentation. Another version of documentation is the preparation of system manual and user manual. These are hard copy documents that contain functioning of the system, its requirements etc. and the procedure for installing and using the programs. While developing software for various applications, these manuals are mandatory. This kind of documentation is known as **external documentation**.

Now you have analysed the problem, derived the logic of the solution, expressed in a flow chart, developed the code in a programming language, translated it after removing the syntax errors, checked the accuracy of the output after removing all the possible logical and run-time errors, and we have documented the program.

Check yourself



1. What is an algorithm?
2. Pictorial representation of algorithm is known as _____.
3. Which flow chart symbol is always used in pair?
4. Which flow chart symbol has one entry flow and two exit flows?
5. Program written in HLL is known as _____.
6. What is debugging?
7. What is an object code?

4.4 Performance evaluation of algorithms

We have developed algorithms for solving various problems. You may think that some of these problems would have been solved by following a different logic. Of course, it is true that the same problem can be solved by different sets of instructions. But an efficient programmer is the one who develops algorithms that require minimum computer resources for execution and give results with high accuracy in lesser time. The performance of an algorithm is evaluated based on the concept of time and space complexity. The algorithm which will be executed faster with minimum amount of memory space is considered as the best algorithm for the problem.

Algorithm-1	Algorithm-2
Step 1: Start	Step 1: Start
Step 2: Input A, B, C	Step 2: Input A, B, C
Step 3: $S = A + B + C$	Step 3: $S = A + B + C$
Step 4: $Avg = S / 3$	Step 4: $Avg = (A + B + C) / 3$
Step 5: Print S, Avg	Step 5: Print S, Avg
Step 6: Stop	Step 6: Stop

Table 4.2 : Algorithms to find the sum and average of three numbers

Let us compare the two algorithms given in Table 4.2, developed to find the sum and average of three numbers. The two algorithms differ in step 4. Algorithm-2 uses two steps (steps 3 and 4) for addition operation on the same data. Naturally, that algorithm will take more time for execution than Algorithm-1. So Algorithm-1 is better for coding.

Now let us take another case, where comparison operations are involved for the selection of a statement. We have already discussed an algorithm to find the largest among three numbers in Example 4.4. The two algorithms given in Table 4.3 can also be used for solving the same problem.

Algorithm-1	Algorithm-2
Step 1: Start	Step 1: Start
Step 2: Input M1, M2, M3	Step 2: Input M1, M2, M3
Step 3: If $M1 > M2$ And $M1 > M3$ Then	Step 3: If $M1 > M2$ Then
Step 4: Print M1	Step 4: Big = M1
Step 5: If $M2 > M1$ And $M2 > M3$ Then	Step 5: Else
Step 6: Print M2	Step 6: Big = M2
Step 7: If $M3 > M1$ And $M3 > M2$ Then	Step 7: If $M3 > Big$ Then Big = M3
Step 8: Print M3	Step 8: Print Big
Step 9: Stop	Step 9: Stop

Table 4.3 : Algorithms to find the largest among three numbers

The algorithm in Example 4.4 has three comparison operations and one logical operation altogether. All these operations are to be carried out only when the largest value is in M3 (the third variable). To identify the speed of execution in each case, let us assume that 1 second is required for one comparison operation. We can see that fastest result will be in 3 seconds and slowest in 4 seconds. So the average speed is 3.5 seconds.

Now let us analyse Algorithm-1 in Table 4.3. There are three **If** statements, each with three comparison operations. If we follow the assumptions specified above, we can see that the result will be obtained in 9 seconds, irrespective of the values in the variables. So the average speed is 9 seconds. But the Algorithm-2 in Table 4.3 uses two **If** structures. The algorithm shows that whatever be the values in the variables, the time required for comparison will be 2 seconds. Thus the average speed is 2 seconds. So, we can say that the Algorithm-2 is better than the other two.

Let us consider one more case where loop is involved. The two algorithms given in Table 4.4 find the sum of all even numbers and sum of all odd numbers between 100 and 200.

Algorithm-1	Algorithm-2
Step 1: Start	Step 1: Start
Step 2: N = 100, ES = 0	Step 2: N = 100, ES = 0, OS = 0
Step 3: Repeat Steps 4 to 6 While (N <= 200)	Step 3: Repeat Steps 4 to 8 While (N <= 200)
Step 4: If Remainder of N/2 = 0 Then	Step 4: If Remainder of N/2 = 0 Then
Step 5: ES = ES + N	Step 5: ES = ES + N
Step 6: N = N + 1	Step 6: Else
Step 7: Print ES	Step 7: OS = OS + N
Step 8: N = 100, OS = 0	Step 8: N = N + 1
Step 9: Repeat Steps 10 to 12 While (N <= 200)	Step 9: Print ES
Step 10: If Remainder of N/2 = 1 Then	Step 10: Print OS
Step 11: OS = OS + N	Step 11: Stop
Step 12: N = N + 1	
Step 13: Print OS	
Step 14: Stop	

Table 4.4 : Algorithms to find sum of even and odd numbers

Algorithm-1 uses two loops. Obviously, time taken will be double for the initialisation, testing and updation of loop control variable compared to Algorithm-2. From the table, it is clear that Algorithm-2 is better and efficient. So, think divergently and differently to develop logic for solving problems.



Let us sum up

Program is a sequence of instructions written in a computer language. The process of programming proceeds through some stages. Preparation of algorithms and flowcharts help develop the logic. The program written in HLL, is known as source code and it is to be converted into machine language. The resultant code is known as object code. The errors occurred in a program has to be removed through a process known as debugging. The translated version is executed by the computer. Proper documentation of the program helps us to modify it at a later stage. While solving problems different logic may be applied, but the performance is measured in terms of time and space complexity.



Learning outcomes

After the completion of this chapter the learner will be able to

- explain various aspects of problem solving.
- develop algorithms for solving problems.
- draw flowcharts to ensure the correctness of algorithms.
- select the best algorithm for solving a problem.

Sample questions

Very short answer type

1. What is an algorithm?
2. What is the role of a computer in problem solving?
3. What is the use of connector in a flow chart?
4. What do you mean by logical errors in a program?

Short answer type

1. What is a computer program? How does an algorithm help to write a program?
2. Write an algorithm to find the sum and average of 3 numbers.
3. Draw a flowchart to display the first 100 natural numbers.
4. What are the limitations of a flow chart?
5. What is debugging?
6. What is the need of documentation for a program?

Long answer type

1. What are the characteristics of an algorithm?
2. What are the advantages of using a flowchart?
3. Briefly explain different phases in programming.

Key concepts

- **C++ character set**
- **Tokens**
 - Keywords
 - Identifiers
 - Literals
 - Punctuators
 - Operators
- **Integrated Development Environment (IDE)**
 - Geany IDE

Introduction to C++ Programming

C++ (pronounced "C plus plus") is a powerful, popular object oriented programming (OOP) language developed by Bjarne Stroustrup. The idea of C++ comes from the C increment operator ++, thereby suggesting that C++ is an added (incremented) version of C language.

The C++ language can be used to practice various programming concepts such as sequence, selection and iteration which we have already discussed in Chapter 4. In this chapter, we will have a brief overview of the fundamentals of C++. We will also familiarise different language processor packages that are used to write C++ programs.

Just like any other language, the learning of C++ language begins with the familiarisation of its basic symbols called characters. The learning hierarchy proceeds through words, phrases (expressions), statements, etc. Let us begin with the learning of characters.

5.1 Character set

As we know, the study of any language, such as English, Malayalam or Hindi begins with the alphabet. Similarly, the C++ language also has its own alphabet. With regard to a programming language the alphabet is known as character set. It is a set of valid symbols, called characters that a language can recognize. A character represents



Dr. Bjarne Stroustrup developed C++ at AT&T Bell Laboratories in Murray Hill, New Jersey, USA. Now he is a visiting Professor at Columbia University and holder of the College of Engineering Chair in Computer Science at Texas A&M University. He has received numerous honours. Initial name of this language was 'C with classes'. Later it was renamed to C++, in 1983.



Bjarne Stroustrup

any letter, digit, or any other symbol. The set of valid characters in a language which is the fundamental units of that language, is collectively known as **character set**. The character set of C++ is categorized as follows:

- (i) Letters : A B C D E F G H I J K L M N O P Q R S T U V
W X Y Z
a b c d e f g h i j k l m n o p q r s t u v w x y z
- (ii) Digits : 0 1 2 3 4 5 6 7 8 9
- (iii) Special characters : + - * / ^ \ () [] { } = < > . ' " \$
, ; : % ! & ? _ (underscore) # @
- (iv) White spaces : Space bar (Blank space), Horizontal Tab (→),
Carriage Return (↵), Newline, Form feed
- (v) Other characters : C++ can process any of the 256 ASCII characters
as data or as literals.



Spaces, tabs and newlines (line breaks) are called white spaces. White space is required to separate adjacent words and numbers.

5.2 Tokens

After learning the alphabet the second stage is learning words constituted by the alphabet (or characters). The term 'token' in the C++ language is similar to the term 'word' in natural languages. **Tokens** are the fundamental building blocks of the program. They are also known as lexical units. C++ has five types of tokens as listed below:

1. Keywords
2. Identifiers
3. Literals
4. Punctuators
5. Operators

5.2.1 Keywords

The words (tokens) that convey a specific meaning to the language compiler are called **keywords**. These are also known as reserved words as they are reserved by the language for special purposes and cannot be redefined for any other purposes. The set of 48 keywords in C++ are listed in Table 5.1. Their meaning will be explained in due course.

asm	continue	float	new	signed	try
auto	default	for	operator	sizeof	typedef
break	delete	friend	private	static	union
case	do	goto	protected	struct	unsigned
catch	double	if	public	switch	virtual
char	else	inline	register	template	void
class	enum	int	return	this	volatile
const	extern	long	short	throw	while

Table 5.1: Keywords of C++

5.2.2 Identifiers

We usually assign names to places, people, objects, etc. in our day to day life, to identify them from one another. In C++ we use identifiers for this purpose. **Identifiers** are the user-defined words that are used to name different program elements such as memory locations, statements, functions, objects, classes etc. The identifiers of memory locations are called *variables*. The identifiers assigned to statements are called *labels*. The identifiers used to refer a set of statements are called *function names*.

While constructing identifiers certain rules are to be strictly followed for their validity in the program. The rules are as follows:

- Identifier is an arbitrary long sequence of letters, digits and underscores (_).
- The first character must be a letter or underscore (_).
- White space and special characters are not allowed.
- Keywords cannot be used as identifiers.
- Upper and lower case letters are treated differently, i.e. C++ is case sensitive.

Examples for some valid identifiers are Count, Sumof2numbers, Average_Height, _1stRank, Main, FOR

The following are some invalid identifiers due to the specified reasons:

- | | |
|---------------|--|
| Sum of Digits | → Blank space is used |
| 1styear | → Digit is used as the first character |
| First.Jan | → Special character (.) is used |
| for | → It is a keyword |



Let us do

Identify invalid identifiers from the following list and give reasons:

Data_rec, _data, ldata, datal, my.file, asm, switch, goto, break

5.2.3 Literals

Consider the case of the Single Window System for the admission of Plus One students. You may have given your date of birth in the application form. As an applicant, your date of birth remains the same throughout your life. Once they are assigned their initial values, they never change their value. In mathematics, we know that the value of π is a constant and the value of gravitational constant 'g' never changes, i.e. it remains 9.8m/s^2 . Like that, in C++, we use the type of tokens called **literals** to represent data items that never change their value during the program run. They are often referred to as constants. Literals can be divided into four types as follows:

1. Integer literals
2. Floating point literals
3. Character literals
4. String literals

Integer literals

Consider the numbers 1776, 707, -273. They are integer constants that identify integer decimal values. The tokens constituted only by digits are called **integer literals** and they are whole numbers without fractional part. The following are the characteristics of integer literals:

- An integer constant must have at least one digit and must not contain any decimal point.
- It may contain either + or – sign as the first character, which indicates whether the number is positive or negative.
- A number with no sign is treated as positive.
- No other characters are allowed.

**Let us do**

Classify the following into valid and invalid integer constants and give reasons for the invalidity:

77,000	70	314.	-5432	+15346
+23267	-.7563	-02281+0	1234E56	-9999



In addition to decimal numbers (base 10), C++ allows the use of octal numbers (base 8) and hexadecimal numbers (base 16) as literals (constants). To express an octal number we have to precede it with a 0 (zero character) and in order to express a hexadecimal number we have to precede it with the characters 0x (zero, x). For example, the integer constants 75, 0113 and 0x4B are all equivalent to each other. All of these represent the same number 75 (seventy-five), expressed as a base-10 numeral, octal numeral and hexadecimal numeral, respectively.

Floating point literals

You may have come across numbers like 3.14159 , 3.0×10^8 , 1.6×10^{-19} and 3.0 during your course of study. These are four valid numbers. The first number is π (Pi), the second one is the speed of light in meter/sec, the third is the electric charge of an electron (an extremely small number) – all of them are approximated, and the last one is the number three expressed as a floating-point numeric literal.

Floating point literals, also known as real constants are numbers having fractional parts. These can be written in one of the two forms called fractional form or exponential form.

A real constant in fractional form consists of signed or unsigned digits including a decimal point between digits. The rules for writing a real constant in fractional form are given below:

- A real constant in fractional form must have at least one digit and a decimal point.
- It may also have either + (plus) or – (minus) sign preceding it.
- A real constant with no sign is assumed to be positive.

A real constant in exponential form consists of two parts: *mantissa* and *exponent*. For instance, 5.8 can be written as $0.58 \times 10^1 = 0.58E1$ where mantissa part is 0.58 (the part appearing before **E**) and exponential part is 1 (the part appearing after **E**). The number E1 represents 10^1 . The rules for writing a real constant in exponential form are given below:

- A real constant in exponent form has two parts: a mantissa and an exponent.
- The mantissa must be either an integer or a valid fractional form.

- The mantissa is followed by a letter **E** or **e** and the exponent.
- The exponent must be an integer.

The following are valid real constants.

52.0	107.5	-713.8	-.00925
453.E-5	1.25E08	.212E04	562.0E09
152E+8	1520E04	-0.573E-7	-.097

Some invalid real constants are given along with the reason:

58,250.262 (Comma is used), 5.8E (No exponent part), 0.58E2.3 (Fractional number is used as exponent).



Classify the following into valid and invalid real constants and justify your answer:

Let us do

77, 00,000	7.0	3.14	-5.0E5.4	+53.45E-6
+532.67,	.756E-3	-0.528E10	1234.56789	34,56.24
4353	+34/2	5.6E	4356	0

Character literals

When we want to store the letter code for gender usually we use 'f' or 'F' for *Female* and 'm' or 'M' for *Male*. Similarly, we may use the letter 'y' or 'Y' to indicate *Yes* and the letter 'n' or 'N' to indicate *No*. These are single characters. When we refer a single character enclosed in single quotes that never changes its value during the program run, we call it a **character literal** or **character constant**.

Note that `x` without single quote is an identifier whereas `'x'` is a character constant. The value of a single character constant is the ASCII value of the character. For instance, the value of `'c'` will be 99 which is the ASCII value of `'c'` and the value of `'A'` will be the ASCII value 65.

C++ language has certain non-graphic character constants, which cannot be typed directly from the keyboard. For example, there is no way to express the Carriage Return or Enter key, Tab key and Backspace key. These non-graphic symbols can be represented by using **escape sequences**, which consists of a backslash (\) followed by one or more characters. It should be noted that even though escape sequences contain more than one character enclosed in single quotes, it uses only one corresponding ASCII code to represent it. That is why they are treated as character constants. Table 5.2 lists escape sequences and corresponding characters.

In Table 5.2, we can also see sequences representing `\'`, `\"` and `\?`. These characters can be typed from the keyboard but when used without escape sequence, they carry a special meaning and have a special purpose. However, if these are to be displayed or printed as it is, then escape sequences should be used. Examples of some valid character constants are: `'s'`, `'S'`, `'$'`, `'\n'`, `'+''`, `'9'`

Some invalid character constants are also given with the reason for invalidity:

`'A'` (No single quotes), `'82'` (More than one character), `"K"` (Double quotes instead of single quotes), `'\g'` (Invalid escape sequence or Multiple characters).

Escape Sequence	Corresponding Non-graphic character
<code>\a</code>	Audible bell (alert)
<code>\b</code>	Back Space
<code>\f</code>	Form feed
<code>\n</code>	New line or Line feed
<code>\r</code>	Carriage Return
<code>\t</code>	Horizontal Tab
<code>\v</code>	Vertical Tab
<code>\\</code>	Back slash
<code>\'</code>	Single quote
<code>\"</code>	Double quote
<code>\?</code>	Question mark
<code>\0</code>	Null character

Table 5.2 : Escape Sequences



C++ represents Octal Number and Hexadecimal Number with the help of escape sequences. The `\On` and `\xHn` represent a number in the Octal Number System and the Hexadecimal Number System respectively.

String literals

Nandana is a student and she lives in Bapuji Nagar. Here, "Nandana" is the name of a girl and "Bapuji Nagar" is the name of a place. These kinds of data may need to be processed with the help of programs. Such data are considered as string constants and they are enclosed within double quotes. A sequence of one or more characters enclosed within a pair of double quotes is called **string constant**. For instance, "Hello friends", "123", "C++", "Baby's Day Out", etc. are valid string constants.



Let us do

Classify the following into different categories of literals.

<code>'a'</code>	<code>"rita"</code>	<code>-124</code>	<code>12.5</code>	<code>-12e-1</code>
<code>"raju's pen"</code>	<code>0</code>	<code>-11.999</code>	<code>'\'</code>	<code>32760</code>

5.2.4 Punctuators

In languages like English, Malayalam, etc. punctuation marks are used for grammatical perfection of sentences. Consider the statement: *Who developed C++?* Here '?' is the punctuation mark that tells that the statement is a question. Similarly at the end of each sentence we put a full stop (.). In the same way C++ also has some special symbols that have syntactic or semantic meaning to the compiler. These are called **punctuators**. Examples are: # ; ' " () [] { }. The purpose of each punctuator will be discussed later.

5.2.5 Operators

When we have to add 5 and 3, we express it as $5 + 3$. Here + is an operator that represents the addition operation. Similarly, C++ has a rich collection of operators. An **operator** is a symbol that tells the compiler about a specific operation. They are the tokens that trigger some kind of operation. The operator is applied on a set of data called **operands**. C++ provides different types of operators like arithmetic, relational, logical, assignment, conditional, etc. We will discuss more about operators in the next chapter.



Classify the following into different categories of tokens.

```
/      -124      +      -12e-1      '"KL01"
Sum    "raju\'s pen"    if    rita      '\\\'
break  }
```

Let us do

5.3 Integrated Development Environment (IDE)

Now we have learned the basic elements of a C++ program. Before we start writing C++ programs, we must know where we will type this program. Like other programming languages, a text editor is used to create a C++ program. The compilers such as GCC (GNU Compiler Collection), Turbo C++, Borland C++, and many other similar compilers provide an Integrated Development Environment (IDE) for developing C++ programs. Many of these IDEs provide facilities for typing, editing, searching, compiling, linking and executing a C++ program. We use Geany IDE (T1@School Ubuntu Linux 12.04) for the purpose of illustrating the procedure for coding, compiling and executing C++ programs.

GCC with Geany IDE

GCC compiler is a free software available with Linux operating system. GCC stands for GNU Compiler Collection and is one of the popular C++ compilers which

works with ISO C++ standard. Geany is a cross-platform IDE for writing, compiling and executing C++ programs.

A. Opening the edit window

The edit window of Geany IDE can be opened from the **Applications** menu of Ubuntu Linux by proceeding as follows:

Applications → Programming → Geany

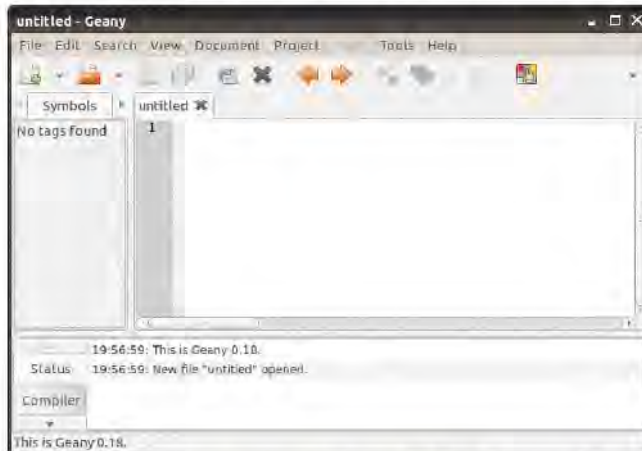



Fig. 5.1: Opening screen of Geany IDE in Ubuntu Linux

In this window, we type the program in a file with the default name **untitled**. To open a new file, choose **File** menu, then select **New** option or click New button  on the toolbar.

b. Saving the program

Once a file is opened, enter the C++ program and save it with a suitable file name with extension **.cpp**. GCC

being a collection of compilers, the extension decides which compiler is to be selected for the compilation of the code. Therefore we have to specify the extension without fail. If we give the file name before typing the program, GCC provides different colours automatically to distinguish the types of tokens used in the program. It also uses indentation to identify the level of statements in the source code. We will discuss the concept of indentation later.

Geany IDE opens its window as shown in Figure 5.1. It has a title bar, menu bar, toolbar, and a code edit area. We can see a tab named **untitled**, which indicates the file name for the opened edit area. If we use Geany 1.24 on Windows operating system, the opening window will be as shown in Figure 5.2. We can see that both of these are quite the same.

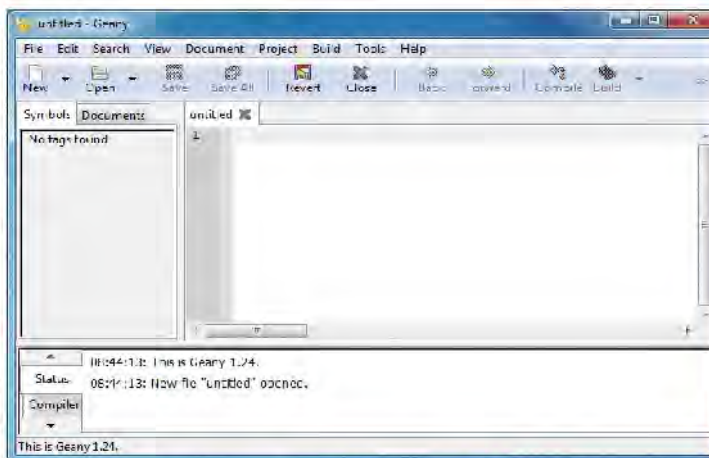


Fig. 5.2: Opening screen of Geany IDE 1.24 in Windows OS

Let us write a simple program given as Program 5.1 and save with the name `welcome.cpp`.

Program 5.1: A program to familiarise the IDE

```
// my first C++ program
#include<iostream>
using namespace std;
int main()
{
    cout << "Welcome to the world of C++";
    return 0;
} //end of program
```

The IDE window after entering Program 5.1 is shown in Figure 5.3. Observe the difference in colours used for the tokens.

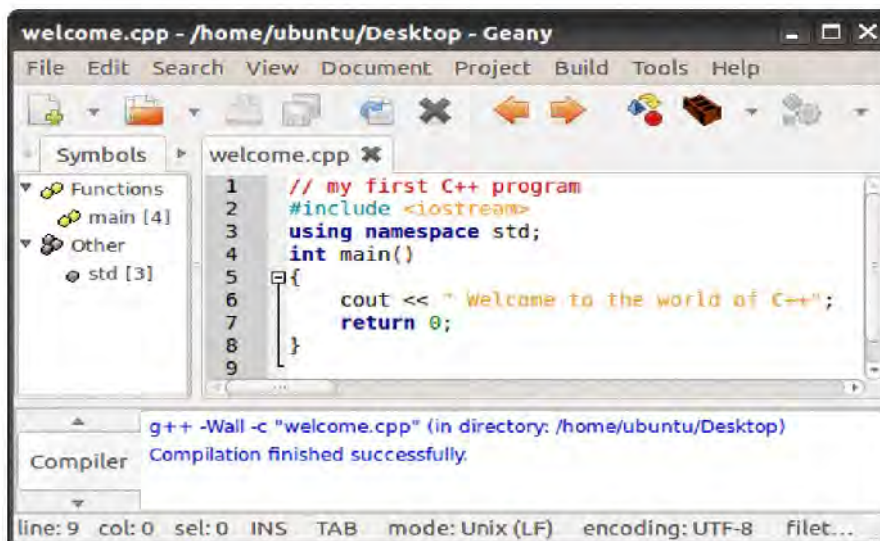



Fig. 5.3: Program saved with a name in Geany IDE


To save the program, choose **File** menu and select **Save** option or use the keyboard shortcut **Ctrl+S**. Alternatively the file can be saved by clicking the Save button  in the toolbar.


It is a good practice to save the program every now and then, just by pressing **Ctrl+S**. This helps to avoid the loss of data due to power failures or due to unexpected system errors. Once the program typing is completed, it is better to save the file before compiling or modifying. Copying the files from the temporary volatile primary memory to permanent non volatile secondary memory for storage is known as saving the program.




C++ program files should have a proper extension depending upon the implementation of C++. Different extensions are followed by different compilers. Examples are .cpp, .cxx, .cc, .c++

C. Compiling and linking the program

The next step is to compile the program and modify it, if errors are detected. For this, choose **Build** menu and select **Compile** option. Alternatively we can also use the Compile button . If there are some errors, those errors will be displayed in the compiler status window at the bottom, otherwise the message **Compilation finished successfully** will be displayed. (refer Figure 5.3).

After successful compilation, choose **Build** menu and select **Build** option for linking or click the Build button  in the toolbar. Now the program is ready for execution.

D. Running/Executing the program

Running the program is the process by which a computer carries out the instructions of a computer program. To run the program, choose **Build** menu and select **Execute** option. The program can also be executed by clicking the Execute button  in the toolbar. The output will be displayed in a new window as shown in Figure 5.4.

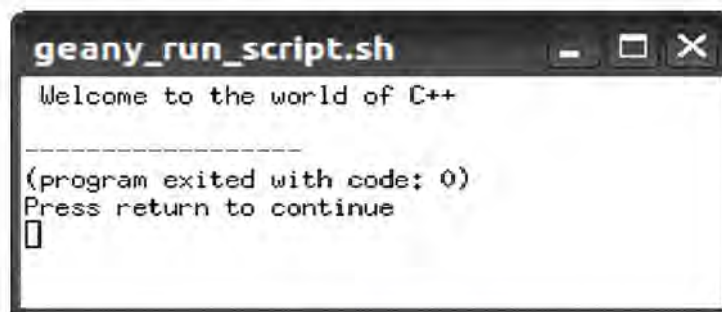



Fig. 5.4: Output window

E. Closing the IDE

Once we have executed the program and desired output is obtained, it can be closed by selecting **Close** option from **File** menu or by clicking the Close button **X** in the active tab or in the title bar. For writing another program, a new file can be opened by the **New** option from the **File** menu or by clicking the New button  in the tool bar. The key combination **Ctrl+N** can also be used for the same.

After developing program, we can come out of Geany IDE by choosing **File** menu and selecting **Quit** option. The same can be achieved by clicking the Close button of the IDE window or by using the key combination **Ctrl+Q**.



Let us do

1. Write a program to print the message "SMOKING IS INJURIOUS TO HEALTH" on screen.
2. Write a program to display the message "TOBACCO CAUSES CANCER" on monitor.



Let us sum up

C++ was developed by Bjarne Stroustrup in early 1980s. C++ has its own character set. Tokens are the smallest unit of a program and are constituted by one or more characters in C++. There are five types of tokens namely keywords, identifiers, literals, punctuators and operators. Programs are written in computer with the help of an editor. Software like GCC and Geany IDE provide facilities to enter the source code in the computer, compile it and execute the object code.



Learning outcomes

After the completion of this chapter the learner will be able to:

- list the C++ character set.
- categorise various tokens.
- identify keywords.
- write valid identifiers.
- classify various literals.
- identify the main components of Geany IDE.
- write, compile and run a simple program.

Sample questions

Very short answer type

- What are the different types of characters in C++ character set?
- What is meant by escape sequences?
- Who developed C++?
- What is meant by tokens? Name the tokens available in C++.
- What is a character constant in C++?
- How are non-graphic characters represented in C++? Give an example.
- Why are the characters \ (slash), ' (single quote), " (double quote) and ? (question mark) typed using escape sequences?
- Which escape sequences represent newline character and null character?
- An escape sequence represents _____ characters.
- Which of the following are valid character/string constants in C++?
'c' 'anu' "anu" mine 'main's' " "
'char' '\ \'
- What is a floating point constant? What are the different ways to represent a floating point constant?
- What are string-literals in C++? What is the difference between character constants and string literals?
- What is the extension of C++ program file used for running?
- Find out the invalid identifiers among the following. Give reason for their invalidity
a) Principal amount b) Continue c) Area d) Date-of-join e) 9B
- A label in C++ is _____.
a) Keyword b) Identifier c) Operator d) Function
- The following tokens are taken from a C++ program. Fill up the given table by placing them at the proper places
(int, cin, %, do, =, "break", 25.7, digit)

Keywords	Identifiers	Literals	Operators

Short answer type

1. Write down the rules governing identifiers.
2. What are tokens in C++? How many types of tokens are allowed in C++? List them.
3. Distinguish between identifiers and keywords.
4. How are integer constants represented in C++? Explain with examples.
5. What are character constants in C++? How are they implemented?

Long answer type

1. Briefly describe different types of tokens.
2. Explain different types of literals with examples.
3. Briefly describe the Geany IDE and its important features.

Key concepts

- **Concept of data types**
- **C++ data types**
- **Fundamental data types**
- **Type modifiers**
- **Variables**
- **Operators**
 - Arithmetic
 - Relational
 - Logical
 - Input/Output
 - Assignment
 - Arithmetic assignment
 - Increment and decrement
 - Conditional
 - sizeof
 - Precedence of operators
- **Expressions**
 - Arithmetic
 - Relational
 - Logical
- **Type conversion**
- **Statements**
 - Declaration
 - Assignment
 - Input /Output
- **Structure of a C++ program**
 - Pre-processor directives
 - Header files
 - Concept of namespace
 - The main() function
 - A sample program
- **Guidelines for coding**

Data Types and Operators

In the previous chapter we familiarised ourselves with the IDE used for the development of C++ programs and also learnt the basic building blocks of C++ language. As we know, data processing is the main activity carried out in computers. All programming languages give importance to data handling. The input data is arranged and stored in computers using some structures. C++ has a predefined template for storing data. The stored data is further processed using operators. C++ also makes provisions for users to define new data types, called user-defined data types.

In this chapter, we will explore the main concepts of the C++ language like data types, operators, expressions and statements in detail.

6.1 Concept of data types

Consider the case of preparing the progress card of a student after an examination. We need data like admission number, roll number, name, address, scores in different subjects, the grades obtained in each subject, etc. Further, we need to display the percentage of marks scored by the student and the attendance in percentage. If we consider a case of scientific data processing, it may require data in the form of numbers representing the velocity of light (3×10^8 m/s), acceleration due to gravity (9.8 m/s), electric charge of an electron (-1.6×10^{-19}) etc.

From these cases, we can infer that data can be of different types like character, integer number, real number, string, etc. In the last chapter we saw that any valid character of C++ enclosed in single quotes represents character data in C++. Numbers without fractions represent integer data. Numbers with fractions represent floating point data and anything enclosed in double quotes represents a string data. Since the data to be dealt with are of many types, a programming language must provide ways and facilities to handle all types of data. C++ provides facilities to handle different types of data by providing data type names. **Data types** are the means to identify the nature of the data and the set of operations that can be performed on the data. Various data types are defined in C++ to differentiate these data characteristics.

In Chapter 4, we used variables to refer data in algorithms. Variables are also used in programs for referencing data. When we write programs in the C++ language, variables are to be declared before their use. Data types are necessary to declare these variables.

6.2 C++ data types

C++ provides a rich set of data types. Based on nature, size and associated operations, they are classified as shown in Figure 6.1. Basically, they are classified into fundamental or built-in data types, derived data types and user-defined data types.

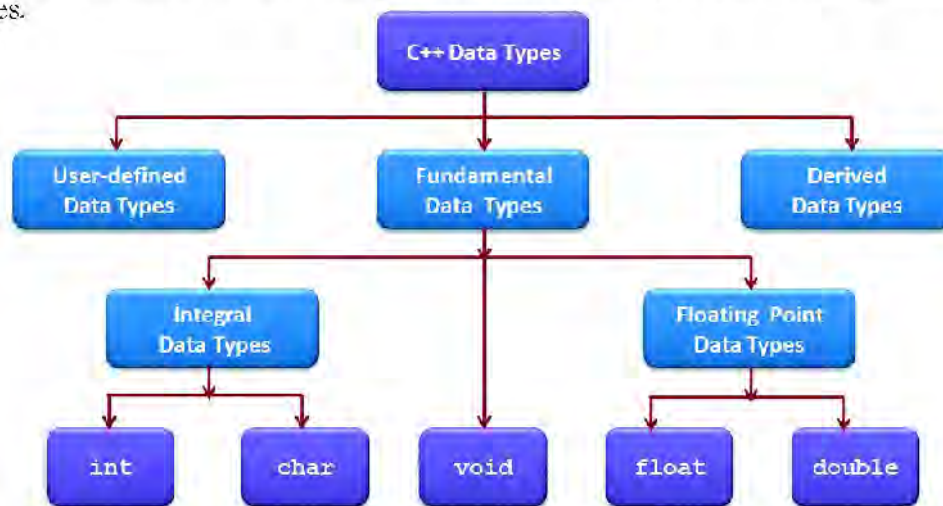


Fig 6.1 : Classification of C++ data types

Fundamental data types

Fundamental data types are defined in C++ compiler. They are also known as built-in data types. They are atomic in nature and cannot be further decomposed of. The five fundamental data types in C++ are char, int, float, double and void. Among these, int and char comes under integral data type as they can handle

only integers. The numbers with fractions (real numbers) are generally known as floating type and are further divided into `float` and `double` based on precision and range.

User-defined data types

C++ is flexible enough to allow programmers to define their own data types. Structure (`struct`), enumeration (`enum`), union, class, etc. are examples for such data types.

Derived data types

Derived data types are constructed from fundamental data types through some grouping or alteration in the size. Arrays, pointers, functions, etc. are examples of derived data types.

6.3 Fundamental data types

Fundamental data types are basic in nature. They cannot be further broken into small units. Since these are defined in compiler, the size (memory space allocated) depends on the compiler. We use the compiler available in GCC and hence the size as well as the range of data supported by the data type are given accordingly. It may be different if you use other compilers like Turbo C++ IDE. The five fundamental data types are described below:

int data type (for integer numbers)

Integers are whole numbers without a fractional part. They can be positive, zero or negative. The keyword **int** represents integer numbers within a specific range. GCC allows 4 bytes of memory for integers belonging to `int` data type. So the range of values that can be represented by `int` data type is from -2147483648 to +2147483647. The data items 6900100, 0, -112, 17, -32768, +32767, etc. are examples of `int` data type. The numbers 22000000000 and -2147483649 do not belong to `int` data type as they are out of the allowed range.

char data type (for character constants)

Characters are the symbols covered by the character set of the C++ language. All letters, digits, special symbols, punctuations, etc. come under this category. When these characters are used as data they are considered as `char` type data in C++. We can say that the keyword **char** represents character literals of C++. Each `char` type data is allowed one byte of memory. The data items 'A', '+', '\t', '0', etc. belong to `char` data type. The `char` data type is internally treated as integers, because computer recognises the character through its ASCII code. Character data is stored in the memory with the corresponding ASCII code. As ASCII codes are integers and need to be stored in one byte (8 bits), the range of `char` data type is from -128 to +127.

float data type (for floating point numbers)

Numbers with a fractional part are called floating point numbers. Internally, floating-point numbers are stored in a manner similar to scientific notation. The number 47281.97 is expressed as 0.4728197×10^5 in scientific notation. The first part of the number, 0.4728197 is called the mantissa. The power 5 of 10 is called exponent. Computers typically use exponent form (*E notation*) to represent floating-point values. In E notation, the number 47281.97 would be 0.4728197E5. The part of the number before the E is the mantissa, and the part after the E is the exponent. In C++, the keyword **float** is used to denote such numbers. GCC allows 4 bytes of memory for numbers belonging to float data type. The numbers of this data type has normally a precision of 7 digits.

double data type (for double precision floating point numbers)

In some cases, floating point numbers require more precision. Such numbers are represented by **double** data type. The range of numbers that can be handled by float type is extended by this data type, because it consumes double the size of float data type. In C++, it is assured that the range and precision of double will be at least as big as float. GCC reserves 8 bytes for storing a double precision value. The precision of double data type is generally 15 digits.

void data type (for null or empty set of values)

The data type **void** is a keyword and it indicates an empty set of data. Obviously it does not require any memory space. The use of this data type will be discussed in detail in Chapter 10.

The size of fundamental data types decreases in the order double, float, int and char.

6.4 Type modifiers

Have you ever seen travel bags that can alter its size/volume to include extra bit of luggage? Usually we don't use that extra space. But the zipper attached with the bag helps us to alter its volume either by increasing it or by decreasing. In C++ too, we need data types that can accommodate data of slightly bigger/smaller size. C++ provides **data type modifiers** which help us to alter the size, range or precision. Modifiers precede the data type name in the variable declaration. It alters the range of values permitted to a data type by altering the memory size and sign of values. Important modifiers are **signed**, **unsigned**, **long** and **short**.

The exact sizes of these data types depend on the compiler and computer you are using. It is guaranteed that:

- a double is at least as big as a float.
- a long double is at least as big as a double.

Each type and their modifiers are listed in Table 6.1 (based on GCC compiler) with their features.

Name	Description	Size	Range
char	Character	1 byte	signed: -128 to 127 unsigned: 0 to 255
short int (short)	Short Integer	2 bytes	signed: -32768 to 32767 unsigned: 0 to 65535
int	Integer	4 bytes	signed: -2147483648 to 2147483647 unsigned: 0 to 4294967295
long int (long)	Long integer	4 bytes	signed: -2147483648 to 2147483647 unsigned: 0 to 4294967295
float	Floating point number	4 bytes	$-3.4 \times 10^{+/-38}$ to $+3.4 \times 10^{+/-38}$ with approximately 7 significant digits
double	Double precision floating point number	8 bytes	$-1.7 \times 10^{+/-308}$ to $+1.7 \times 10^{+/-308}$ with approximately 15 significant digits
long double	Long double precision floating point number	12 bytes	$-3.4 \times 10^{+/-4932}$ to $+3.4 \times 10^{+/-4932}$ With approximately 19 significant digits

Table 6.1: Data type and type modifiers



The values listed in Table 6.1 are only sample values to give you a general idea of how the types differ. The values for any of these entries may be different on your system.

6.5 Variables

Memory locations are to be identified to refer data. **Variables** are the names given to memory locations. These are identifiers of C++ by which memory locations are referenced to store or retrieve data. The size and nature of data stored in a variable depends on the data type used to declare it. There are three important aspects for a variable.

i. Variable name

It is a symbolic name (identifier) given to the memory location through which the content of the location is referred to.

ii. Memory address

The RAM of a computer consists of collection of cells each of which can store one byte of data. Every cell (or byte) in RAM will be assigned a unique address to refer it. All the variables are connected to one or more memory locations in RAM. The base address of a variable is the starting address of the allocated memory space. In the normal situation, the address is given implicitly by the compiler. The address is also called the *L-value* of a variable. In Figure 6.2 the base address of the variable **Num** is 1001.

iii. Content

The value stored in the location is called the content of the variable. This is also called the *R-value* of the variable. Type and size of the content depends on the data type of the variable.

Figure 6.2, shows the memory representation of a variable. Here the variable name is **Num** and it consumes 4 bytes of memory at memory addresses 1001, 1002, 1003 and 1004. The content of this variable is 18. That is the *L-value* of **Num** is 1001 and the *R-value* is 18.

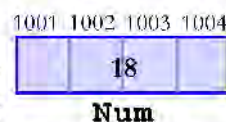


Fig. 6.2 : Memory representation of a Variable

6.6 Operators

Operators are tokens constituted by predefined symbols that trigger computer to carry out operations. The participants of an operation are called **operands**. An operand may be either a constant or a variable.

For example, $a+b$ triggers an arithmetic operation in which $+$ (addition) is the operator and a, b are operands. Operators in C++ are classified based on various criteria. Based on number of operands required for the operation, operators are classified into three. They are unary, binary and ternary.

Unary operators

A unary operator operates on a single operand. Commonly used unary operators are $\text{unary}+$ (positive) and $\text{unary}-$ (negative). These are used to represent the sign of a number. If we apply $\text{unary}+$ operator on a signed number, the existing sign will not change. If we apply $\text{unary}-$ operator on a signed number, the sign of the existing

number will be negated. Examples of the use of unary operators are given in Table 6.2.

Some other examples of unary operators are increment (++) and decrement (--) operators.

Binary operators

Binary operators operate on two operands. Arithmetic operators, relational operators, logical operators, etc. are commonly used binary operators.

Ternary operator

Ternary operator operates on three operands. The typical example is the conditional operator (? :).

The operations triggered by the operators mentioned above will be discussed in detail in the coming sections and some of them will be dealt with in Chapter 7.

Based on the nature of operation, operators are classified into arithmetic, relational, logical, input/output, assignment, short-hand, increment/decrement, etc.

6.6.1 Arithmetic operators

Arithmetic operators are defined to perform basic arithmetic operations such as addition, subtraction, multiplication and division. The symbols used for this are +, -, *, and / respectively. C++ also provides a special operator, % (modulus operator) for getting remainder during division. All these operators are binary operators. Note that + and - are used as unary operators too. The operands required for these operations are numeric data. The result of these operations will also be numeric. Table 6.3 shows some examples of binary arithmetic operations.

Variable x	Unary + +x	Unary- -x
8	8	-8
0	0	0
-9	-9	9

Table 6.2 : Unary operators

Variable x	Variable y	Addition x + y	Subtraction x - y	Multiplication x * y	Division x / y
10	5	15	5	50	2
-11	3	-8	-14	-33	-3.66667
11	-3	8	14	-33	-3.66667
-50	-10	-60	-40	500	5

Table 6.3 : Arithmetic operators

Modulus operator (%)

The modulus operator, also called as mod operator, gives the remainder value during arithmetic division. This operator can only be applied over integer operands.

Table 6.4 shows some examples of modulus operation. Note that the sign of the result is the sign of the first operand. Here in the table the first operand is **x**.

Variable x	Variable y	Modulus Operation x % y	Variable x	Variable y	Modulus Operation x % y
10	5	0	100	100	0
5	10	5	32	11	10
-5	11	-5	11	-5	1
5	-11	5	-11	5	-1
-11	-5	-1	-5	-11	-5

Table 6.4 : Operations using Modulus operator

Check yourself



1. Arrange the fundamental data types in ascending order of size.
2. The name given to a storage location is known as _____.
3. Name a ternary operator in C++.
4. Predict the output of the following operations if $x = -5$ and $y = 3$ initially:
 - a. $-x$
 - b. $-y$
 - c. $-x + -y$
 - d. $-x - y$
 - e. $x \% -11$
 - f. $x + y$
 - g. $x \% y$
 - h. x / y
 - i. $x * -y$
 - j. $-x \% -5$

6.6.2 Relational operators

Relational operators are used for comparing numeric data. These are binary operators. The result of any relational operation will be either **True** or **False**. In C++, True is represented by **1** and False is represented by **0**. There are six relational operators in C++. They are **<** (*less than*), **>** (*greater than*), **<=** (*less than or equal to*), **>=** (*greater than or equal to*), **==** (*equal to*) and **!=** (*not equal to*). Note that equality checking requires two equal symbols (**==**). Some examples for the use of various relational operators and their results are shown in Table 6.5.

m	n	m<n	m>n	m<=n	m>=n	m!=n	m==n
12	5	0	1	0	1	1	0
-7	2	1	0	1	0	1	0
4	4	0	0	1	1	0	1

Table 6.5 : Operations using Relational operators

6.6.3 Logical operators

Using relational operators, we can compare values. Examples are $3 < 5$, $\text{num} != 10$, etc. These comparison operations are called relational expressions in C++. In some cases, two or more comparisons may need to be combined. In Mathematics we may use expressions like $a > b > c$. But in C++ it is not possible. We have to separate this into two, as $a > b$ and $b > c$ and these are to be combined using the logical operator **&&**, i.e. $(a > b) \&\& (b > c)$. The result of such logical combinations will also be either True or False (i.e. 1 or 0). The logical operators are **&&** (logical AND), **||** (logical OR) and **!** (logical NOT).

Logical AND (&&) operator

If two relational expressions E1 and E2 are combined using logical AND (**&&**) operator, the result will be 1 (True) only if both E1 and E2 have values 1 (True). In all other cases the result will be 0 (False). The results of evaluation of **&&** operation for different possible combination of inputs are shown in Table 6.6.

E1	E2	E1&&E2
0	0	0
0	1	0
1	0	0
1	1	1

Table 6.6 : Logical AND

Examples: $10 > 5 \&\& 15 < 25$ evaluates to 1 (True)

$10 > 5 \&\& 100 < 25$ evaluates to 0 (False)

Logical OR (||) operator

If two relational expressions E1 and E2 are combined using logical OR (**||**) operator, the result will be 0 (False) only if both E1 and E2 are having value 0 (False). In all other cases the result will be 1 (True). The results of evaluation of **||** operation for different possible combination of inputs are shown in Table 6.7.

E1	E2	E1 E2
0	0	0
0	1	1
1	0	1
1	1	1

Table 6.7 : Logical OR

Examples: $10 > 5 || 100 < 25$ evaluates to 1 (True)

$10 > 15 || 100 < 90$ evaluates to 0 (False)

Logical NOT operator (!)

This operator is used to negate the result of a relational expression. This is a unary operation. The results of evaluation of ! operator for different possible inputs are shown in Table 6.8.

E1	!E1
0	1
1	0

Table 6.8 :
Logical NOT

Example: $!(100 < 2)$ evaluates to 1 (True)

$!(100 > 2)$ evaluates to 0 (False)

6.6.4 Input / Output operators

Usually input operation requires user's intervention. In the process of input operation, the data given through the keyboard is stored in a memory location. C++ provides **>>** operator for this operation. This operator is known as *get from* or *extraction* operator. This symbol is constituted by two greater than symbols.

Similarly in output operation, data is transferred from RAM to an output device. Usually the monitor is the standard output device to get the results directly. The operator **<<** is used for output operation and is called *put to* or *insertion* operator. It is constituted by two less than symbols.

6.6.5 Assignment operator (=)

When we have to store a value in a memory location, assignment operator (=) is used. This is a binary operator and hence two operands are required. The first operand should be a variable where the value of the second operand is to be stored. Some examples are shown in table 6.9.

Item	Description
$a=b$	The value of variable b is stored in a
$a=3$	The constant 3 is stored in variable a

Table 6.9 : Assignment operator

We discussed the usage of the relational operator **==** in Section 6.6.2. See the difference between these two operators. The **=** symbol assigns a value to a variable, whereas **==** symbol compares two values and gives True or False as the result.

6.6.6 Arithmetic assignment operators

A simple arithmetic statement can be expressed in a more condensed form using arithmetic assignment operators. For example, $a=a+10$ can be represented as **$a+=10$** . Here **+=** is an arithmetic assignment operator. This method is applicable

to all arithmetic operators and they are shown in Table 6.10. The arithmetic assignment operators in C++ are `+=`, `-=`, `*=`, `/=`, `%=`. These are also known as C++ short-hands. These are all binary operators and the first operand should be a variable. The use of these operators makes the two operations (arithmetic and assignment) faster than the usual method.

Arithmetic assignment operation	Equivalent arithmetic operation
<code>x += 10</code>	<code>x = x + 10</code>
<code>x -= 10</code>	<code>x = x - 10</code>
<code>x *= 10</code>	<code>x = x * 10</code>
<code>x /= 10</code>	<code>x = x / 10</code>
<code>x %= 10</code>	<code>x = x % 10</code>

Table 6.10 : C++ short hands

6.6.7 Increment (++) and Decrement (--) operators

Increment and decrement operators are two special operators in C++. These are unary operators and the operand should be a variable. These operators help keeping the source code compact.

Increment operator (++)

This operator is used for incrementing the content of an integer variable by one. This can be written in two ways: `++x` (pre increment) and `x++` (post increment). Both are equivalent to `x=x+1` as well as `x+=1`.

Decrement operator (--)

As a counterpart of increment operator, there is a decrement operator which decrements the content of an integer variable by one. This operator is also used in two ways: `--x` (pre decrement) and `x--` (post decrement). These are equivalent to `x=x-1` and `x-=1`.

The two usages of these operators are called prefix form and postfix form of increment/decrement operation. Both the forms make the same effect on the operand variable, but the mode of operation will be different when these are used with other operators.

Prefix form of increment/decrement operators

In the prefix form, the operator is placed before the operand and the increment/decrement operation is carried out first. The incremented/decremented value is used for the other operations. So, this method is often called *change, then use* method.

Consider the variables `a`, `b`, `c` and `d` with values `a=10`, `b=5`. If an operation is specified as `c=++a`, the value of `a` will be 11 and that of `c` will also be 11. Here the value of `a` is incremented by 1 at first and then the changed value of `a` is assigned

to c. That is why both the variables get the same value. Similarly, after the execution of `d=--b` the value of d and b will be 4.

Postfix form of increment/decrement operators

When increment/decrement operation is performed in postfix form, the operator is placed after the operand. The current value of the variable is used for the remaining operations and after that the increment/decrement operation is carried out. So, this method is often called *use, then change* method.

Consider the same variables used above with the same initial values. After the operation performed with `c=a++`, the value of a will be 11, but that of c will be 10. Here the value of a is assigned to c at first and then a is incremented by 1. That is, before changing the value of a it is used to assign to c. Similarly, after the execution of `d=b--` the value of d will be 5 but that of b will be 4.

6.6.8 Conditional operator (?:)

This is a ternary operator applied over three operands. The first operand will be a logical expression (condition) and the remaining two are values. They can be constants, variables or expressions. The condition will be checked first and if it is 'True', the second operand will be selected to get the value, otherwise the third operand will be selected. Its syntax is:

```
Expression1? Expression2: Expression3
```

Let us see the operation in the following:

```
result = score>50 ? 'p' : 'f'
```

If the value of `score` is greater than 50 then the value 'p' is assigned to the variable `result`, else value 'f' is assigned to `result`. More about this operator will be discussed in Chapter 7.

6.6.9 sizeof operator

The operator `sizeof` is a unary compile-time operator that returns the amount of memory space in bytes allocated for the operand. The operand can be a constant, a variable or a data type. The syntax followed is given below:

- `sizeof (data_type)`
- `sizeof variable_name`
- `sizeof constant`

It is to be noted that when data type is used as the operand for `sizeof` operator, it should be given within a pair of parentheses. For the other operands parentheses are not compulsory. Table 6.11 shows different forms of usages of `sizeof` operator.

Item	Description
<code>sizeof(int)</code>	Gives the value 4 (In GCC, size of <code>int</code> data type is 4 bytes)
<code>sizeof 3.2</code>	Returns 8 (A floating point constant will be taken as <code>double</code> type data)
<code>sizeof p;</code>	If <code>p</code> is <code>float</code> type variable, it gives the value 4.

Table 6.11: Various usages of `sizeof` operator

6.6.10 Precedence of operators

Let us consider the case where different operators are used with the required operands. We should know in which order the operations will be carried out. C++ gives priority to the operators for execution. During evaluation, pair of parentheses is given the first priority. If the expression is not parenthesised, it is evaluated according to the predefined precedence order. The order of precedence for the operators is given in Table 6.12. In an expression, if the operators of the same priority level occur, the precedence of execution will be from left to right in most of the cases.

Priority	Operations
1	() parentheses
2	++, --, !, Unary+, Unary -, sizeof
3	* (multiplication), / (division), % (Modulus)
4	+ (addition), - (subtraction)
5	< (less than), <= (less than or equal to), > (greater than), >= (greater than or equal to)
6	== (equal to), != (not equal to)
7	&& (logical AND)
8	(logical OR)
9	? : (Conditional expression)
10	= (Assignment operator), *=, /=, %=(arithmetic assignment operators)
11	, (Comma)

Table 6.12: Precedence of operators

Consider the variables with values: `a=3, b=5, c=4, d=2, x`

After the operations specified in `x = a + b * c - d`, the value in `x` will be 21. Here * (multiplication) has higher priority than + (addition) and - (subtraction). Therefore the variables `b` and `c` are multiplied, then that result is added to `a`. From that result, `d` is subtracted to get the final result.

It is important to note that the operator priority can be changed in an expression as per the need of the programmer by using parentheses (). For example, if $a=5$, $b=4$, $c=3$, $d=2$ then the result of $a+b-c*d$ will be 3. Suppose the programmer wants to perform subtraction first and then the addition and multiplication, you need to use proper parentheses as $(a+(b-c))*d$. Now the output will be 12. For changing operator priority, brackets [] and braces {} cannot be used.



The operator precedence may be different for different types of compilers. Turbo C++ gives higher precedence to prefix increment / decrement than its postfix form.

For example, if a is initially 5, the values of b and a after $b=a++ + ++a$ are 12 and 7 respectively. This is equivalent to the set of statements $a=a+1$ (prefix expansion), $b=a+a$, and $a=a+1$ (postfix expansion).

6.7 Expressions

An expression is composed of operators and operands. The operands may be either constants or variables. All expressions can be evaluated to get a result. This result is known as the value returned by the expression. On the basis of the operators used, expressions are mainly classified into arithmetic expressions, relational expressions and logical expressions.

6.7.1 Arithmetic expressions

An expression in which only arithmetic operators are used is called arithmetic expression. The operands are numeric data and they may be variables or constants. The value returned by these expressions is also numeric. Arithmetic expressions are further classified into integer expressions, floating point (real) expressions and constant expressions.

Integer expressions

If an arithmetic expression contains only integer operands, it is called integer expression and it produces an integer result after performing all the operations given in the expression. For example, if x and y are integer variables, some integer expressions and their results are shown in Table 6.13. Note that all the above expressions produce integer values as the results.

x	y	$x + y$	x / y	$-x + x * y$	$5 + x / y$	$x \% y$
5	2	7	2	5	7	1
6	3	9	2	12	7	0

Table 6.13: Integer expressions and their results

Floating point expressions (Real expressions)

An arithmetic expression that is composed of only floating point data is called floating point or real expression and it returns a floating point result after performing all the operations given in the expression. Table 6.14 shows some real expressions and their results, assuming that x and y are floating point variables.

x	y	$x + y$	x / y	$-x + x * y$	$5 + x / y$	$x * x / y$
5.0	2.0	7.0	2.5	5.0	7.5	12.5
6.0	3.0	9.0	2.0	12.0	7.0	12.0

Table 6.14: Floating point expressions and their results

It can be seen that all the above expressions produce floating point values as the results.

In an arithmetic expression, if all the operands are constant values, then it is called **constant expression**. The expression $20 + 5 / 2.0$ is an example. The constants like 15, 3.14, 'A' are also known as constant expressions.

6.7.2 Relational expressions

When relational operators are used in an expression, it is called relational expression and it produces Boolean type results like True (1) or False (0). In these expressions, the operands are numeric data. Let us see some examples of relational expressions in Table 6.15.

x	y	$x > y$	$x == y$	$x + y != y$	$x - 2 == y + 1$	$x * y == 6 * y$
5.0	2.0	1 (True)	0 (False)	1 (True)	1 (True)	0 (False)
6	13	0 (False)	0 (False)	1 (True)	0 (False)	1 (True)

Table 6.15: Relational expressions and their results

We know that arithmetic operators have higher priority than relational operators. So when arithmetic expressions are used on either side of a relational operator, arithmetic operations will be carried out first and then the results are compared. The table contains some expressions in which both arithmetic and relational operators are involved. Though they contain mixed type of operators, they are called relational expressions since the final result will be either True or False.

6.7.3 Logical expressions

Logical expressions combine two or more relational expressions with logical operators and produce either True or False as the result. A logical expression may contain constants, variables, logical operators and relational operators. Let us see some examples in Table 6.16.

x	y	$x \geq y \ \&\& \ x == 20$	$x == 5 \ \ y == 0$	$x == y \ \&\& \ y + 2 == 0$	$! (x == y)$
5.0	2.0	0 (False)	1 (True)	0 (False)	1 (True)
20	13	1 (True)	0 (False)	0 (False)	1 (True)

Table 6.16: Logical expressions and their results

As seen in Table 6.16, though some expressions consist of arithmetic and relational operators in addition to logical operators, the expressions are considered as logical expressions. This is because the operation carried out at last will be the logical operation and the result will be either True or False.

Check yourself



- Predict the output of the following operations if $x=5$ and $y=3$.
 - $x \geq 10 \ \&\& \ y \geq 4$
 - $x \geq 1 \ \&\& \ y \geq 3$
 - $x \geq 1 \ || \ y \geq 4$
 - $x \geq 1 \ || \ y \geq 3$
- Predict the output if $p=5$, $q=3$, $r=2$
 - $++p - q * r / 2$
 - $p * q -- + r$
 - $p - q - r * 2 + p$
 - $p += 5 * q + r * r / 2$

6.8 Type conversion

As discussed earlier arithmetic expressions are of two types, integer expressions and real expressions. In both cases, the operands involved in the arithmetic operation are of the same data type. But there are situations where different types of numeric data may be involved. For example in C++, the integer expression $5 / 2$ gives 2 and the real expression $5.0 / 2.0$ gives 2.5. But what will the result of $5 / 2.0$ or $5.0 / 2$ be? Conversion techniques are applied in such situations. The data type of one operand will be converted to another. It is called **type conversion** and can be done in two ways: implicitly and explicitly.

6.8.1 Implicit type conversion (Type promotion)

Implicit type conversion is performed by C++ compiler internally. In expressions where different types of data are involved, C++ converts the lower sized operands to the data type of highest sized operand. Since the conversion is always from lower type to higher, it is also known as **type promotion**. Data types in the decreasing order of size are as follows: long double, double, float, unsigned long, long int and unsigned int / short int. The type of the result will also be the type of the highest sized operand.

For example, the expression $5 / 2 * 3 + 2.5$ gives the result 8.5. The evaluation steps are as follows:

- Step 1: $5 / 2 \rightarrow 2$ (Integer division)
- Step 2: $2 * 3 \rightarrow 6$ (Integer multiplication)
- Step 3: $6 + 2.5 \rightarrow 8.5$ (Floating point addition, 6 is converted into 6.0)

6.8.2 Explicit type conversion (Type casting)

Unlike implicit type conversion, sometimes the programmer may decide the data type of the result of evaluation. This is done by the programmer by specifying the data type within parentheses to the left of the operand. Since the programmer explicitly casts a data to the desired type, it is known as explicit type conversion or **type casting**. Usually, type casting is applied on the variables in the expressions. More examples will be discussed in Section 6.9.2.

6.9 Statements

Can you recollect the learning hierarchy of a natural language? Alphabet, words, phrases, sentences, paragraphs and so on. In the learning process of C++ language we have covered character set, tokens and expressions. Now we have come to the stage where we start communication with the computer sensibly and meaningfully with the help of statements. **Statements** are the smallest executable unit of a programming language. C++ uses the symbol semicolon (;) as the delimiter of a statement. Different types of statements used in C++ are declaration statements, assignment statements, input statements, output statements, control statements etc. Each statement has its own purpose in a C++ program. All these statements except declaration statements are executable statements as they possess some operations to be done by the computer. Executable statements are the instructions to the computer. The execution of control statements will be discussed in Chapter 7. Let us discuss the other statements.

6.9.1 Declaration statements

Every user-defined word should be defined in the program before it is used. We have seen that a variable is a user-defined word and it is an identifier of a memory location. It must be declared in the program before its use. When we declare a variable, we tell the compiler about the type of data that will be stored in it. The syntax of variable declaration is:

```
data_type <variable1>[, <variable2>, <variable3>, ...];
```

The `data_type` in the syntax should be any valid data type of C++. The syntax shows that when there are more than one variables in the declaration, they are separated by comma. The declaration statement ends with a semicolon. Typically, variables are declared either just before they are used or at the beginning of the

program. In the syntax, everything given inside the symbols [and] are optional. The following statements are examples for variable declaration:

```
int rollnumber;
double wgpa, avg_score;
```

The first statement declares the variable `rollnumber` as **int** type so that it will be allocated four bytes of memory (*as per GCC*) and it can hold an integer number within the range from -2147483648 to +2147483647. The second statement defines the identifiers `wgpa` and `avg_score` as variables to hold data of **double** type. Each of them will be allocated 8 bytes of memory. The memory is allocated to the variables during the compilation of the program.

Variable initialisation

We saw, in Section 6.5, that a variable is associated with two values: L-value (its address) and R-value (its content). When a variable is declared, a memory location with an address will be allocated for it. What will its content be? It is not blank or 0 or space! If the variable is declared with **int** data type, the content or R-value will be any integer within the allowed range. But this number cannot be predicted or will not always be the same. So we call it *garbage value*. When we store a value into the variable, the existing content will be replaced by the new one. The value can be stored in the variable either at the time of compilation or execution. Supplying value to a variable at the time of its declaration is called **variable initialisation**. This value will be stored in the respective memory location during compile-time. The assignment operator (=) is used for this. It can be done in two ways as given below:

```
data_type variable = value;
OR
data_type variable(value)
```

The statements: `int xyz = 120;` and `int xyz(120);` are examples of variable initialisation statements. Both of these statements declare an integer variable `xyz` and store the value 120 in it as shown in Figure 6.3.

More examples are:

```
float val=0.12, b=5.234;
char k='A';
```

120

xyz

Fig. 6.3: Variable initialisation

A variable can also be initialised during the execution of the program and is known as dynamic initialisation. This is done by assigning an expression to a variable as shown in the following statements:

```
float product = x * y;
float interest = p*n*r/100.0;
```

In the first statement, the variable `product` is initialised with the product of the values stored in `x` and `y` at runtime. In the second case, the expression `p*n*r/100.0` is evaluated and the value returned by it will be stored in the variable `interest`.

Note that during dynamic initialisation, the variables included in the expression at the right of assignment operator should have valid data. Otherwise it will produce unexpected results.

const – The access modifier

It is a good practice to use symbolic constants rather than using numeric constants directly. For example, we can use symbolic names like `Pi` instead of using `22.0/7.0` or `3.14`. The keyword **const** is used to create such symbolic constants whose value can never be changed during execution. Consider the following statement:

```
float pi=3.14;
```

The floating point variable **pi** is initialised with the value 3.14. The content of **pi** can be changed during the execution of the program. But if we modify the declaration as:

```
const float pi=3.14;
```

the value of **pi** remains constant (unaltered) throughout the execution of the program. The read/write accessibility of the variable is modified as read only. Thus, the **const** acts as an access modifier.



During software development, larger programs are developed using collaborative effort. Several people may work together on different portions of the same program. They may share the same variable. In these situations, there may be occasions where one may modify the content of the variable which will adversely affect other person's coding. In these situations we have to keep the content of variables unaffected by the activity of others. This can be done by using 'const'.

6.9.2 Assignment statements

When the assignment operator (`=`) is used to assign a value to a variable, it forms an assignment statement. It can take any of the following syntax:

```
variable = constant;
variable1 = variable2;
variable = expression;
variable = function();
```

In the third case, the result of the expression is stored in the variable. Similarly, in the fourth case, the value returned by the function is stored. The concept of functions will be discussed in Chapter 10.

Some examples of assignment statements are given below:

```
A = 15;           b = 5.8;
c = a + b;        c = a * b;
d = (a + b) * (c + d);  r = sqrt(25);
```

In the last example, `sqrt()` is a function that assigns the square root of 25 to the variable `r`.

The left hand side (LHS) of an assignment statement must be a variable. During execution, the expression at the right hand side (RHS) is evaluated first. The result is then assigned (stored) to the variable at LHS.

Assignment statement can be chained for doing multiple assignments at a time. For instance, the statement `x=y=z=13;` assigns the value 13 in three variables in the order of `z`, `y` and `x`. The variables should be declared before this assignment. If we assign a value to a variable, the previous value in it, if any, will be replaced by the new value.

Type compatibility

During the execution of an assignment statement, if the data type of the RHS expression is different from that of the LHS variable, there are two possibilities.

- The size of the data type of the variable at LHS is higher than that of the variable or expression at RHS. In this case data type of the value at RHS is promoted (type promotion) to that of the variable at LHS. Consider the following code snippet:

```
int a=5, b=2;
float p, q;
p = b;
q = a / p;
```

Here the data type of `b` is promoted to `float` and 2.0 is stored in `p`. When the expression `a/p` is evaluated, the result will be 2.5 due to the type promotion of `a`. So, `q` will be assigned with 2.5.

- The second possibility is that the size of the data type of LHS variable is smaller than the size of RHS value. In this case, the higher order bits of the result will be truncated to fit in the variable location of LHS. The following code illustrates this.

```
float a=2.6;
int p, q;
p = a;
q = a * 4;
```

Here the value of `p` will be 2 and that of `q` will be 10. The expression `a*4` is evaluated to 10.4, but `q` being `int` type it will hold only 10.

Programmer can apply the explicit conversion technique to get the desired results when there are mismatches in the data types of operands. Consider the following code segment.

```
int p=5, q=2;
float x, y;
x = p/q;
y = (x+p)/q;
```

After executing the above code, the value of x will be 2.0 and that of y will be 3.5. The expression p/q being an integer expression gives 2 as the result and is stored in x as floating point value. In the last statement, the pair of parentheses gives priority to $x+p$ and the result will be 7.0 due to the type promotion of p . Then the result 7.0 will be the first operand for the division operation and hence the result will be 3.5 since q is converted into float . If we have to get the floating point result from p/q to store in x , the statement should be modified as $x = (\text{float}) p/q$; or $x = p/(\text{float}) q$; by applying type casting.

6.9.3 Input statements

Input statement is a means that allows the user to store data in the memory during the execution of the program. We saw that the *get from* or *extraction* operator (\gg) specifies the input operation. The operands required for this operator are the input device and a location in RAM where data is to be stored. Keyboard being a standard console device, the stream (sequence) of data is extracted from the keyboard and stored in memory locations identified by variables. Since C++ is an object oriented language, keyboard is considered as the standard input stream device and is identified as an object by the name **cin** (pronounced as 'see in'). The simplest form of an input statement is:

```
streamobject >> variable;
```

Since we use keyboard as the input device, the **streamobject** in the syntax will be substituted by **cin**. The operand after the \gg operator should strictly be a variable. For example, the following statement reads data from the keyboard and stores in the variable **num**.

```
cin >> num;
```

Figure 6.4 shows how data is extracted from keyboard and stored in the variable.

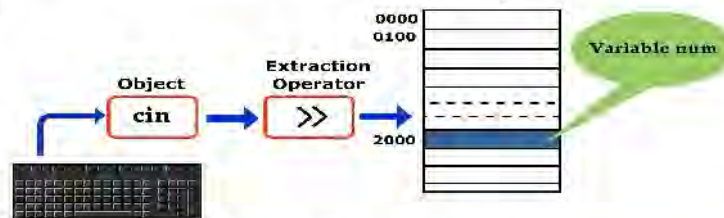


Fig 6.4 : Input procedure in C++

6.9.2 Output statements

Output statements make the results available to users through any output device. The *put to* or *insertion* operator (`<<`) is used to specify this operation. The operands in this case are the output device and the data for the output. The syntax of an output statement is:

```
streamobject << data;
```

The streamobject may be any output device and the data may be a constant, a variable or an expression. We use monitor as the commonly used output device and C++ identifies it as an object by the name **cout** (pronounced as 'see out'). The following are some examples of output statement with monitor as the output device:

```
cout << num;
cout << "hello friends";
cout << num+12;
```

The first statement displays the content of the variable **num**. The second statement displays the string constant "hello friends" and the last statement shows the value returned by the expression `num+12` (assuming that `num` contains numeric value). Figure 6.5 shows how data is inserted into the output stream object (monitor) from the memory location **num**.

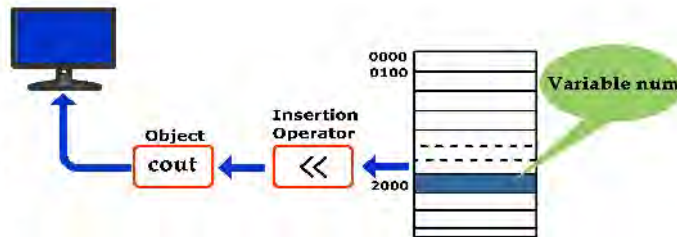


Fig. 6.5: Output procedure in C++



The tokens `cin` and `cout` are not keywords. They are predefined words that are not part of the core C++ language, and you are allowed to redefine them. They are defined in libraries required by the C++ language standard. Needless to say, using a predefined identifier for anything other than its standard meaning can be confusing and dangerous and such practice should be avoided. The safest and easiest practice is to treat all predefined identifiers as if they were keywords.

Cascading of I/O operators

Suppose you want to input three values to different variables, say `x`, `y`, and `z`. You may use the following statements:

```
cin>>x;
cin>>y;
cin>>z;
```

But these three statements can be combined to form a single statement as given below:

```
cin>>x>>y>>z;
```

The multiple use of input or output operators in a single statement is called **cascading of I/O operators**. In the use of cascading of input operators, the values input are assigned to the variables from left to right. In the example `cin>>x>>y>>z;` the first value is assigned to `x`, the second to `y` and the third to `z`. While entering values to the variables `x`, `y` and `z` during execution the values should be separated by space bar, tab, or carriage return.

Similarly, if you want to display the contents of different variables (say `x`, `y`, `z`), use the following statement:

```
cout<<x<<y<<z;
```

If variables, constants and expressions appear together for output operations, the above technique can be applied as in the following example:

```
cout<<"The number is: "<<z;
```

While cascading output operators, the values for the output will be retrieved from right to left. Consider the code fragment given below:

```
int x=5;
cout<<x<<' \t'<<++x;
```

The output of this code will be: 6 6

It will not be: 5 6

It is to be noted that both `<<` and `>>` operators cannot be used in a single statement.

In the statement `x=y=z=5;` the `=` operator is cascaded. Here also the cascading is from right to left.

6.10 Structure of a C++ program

We are now in a position to solve simple problems by using the statements we discussed so far. But a set of statements alone does not constitute a program. A C++ program has a typical structure. It is a collection of one or more functions. A function means the set of instructions to perform a particular task referred to by a name. Since there can be many functions in a C++ program, they are usually identified by unique names. The most essential function needed for every C++ program is the **main()** function.

The structure of a simple C++ program is given below:

```
#include <header file>
using namespace identifier;
int main()
{
    statements;
    :
    :
    :
    return 0;
}
```

The first line is called preprocessor directive and the second line is the namespace statement. The third line is the function header which is followed by a set of statements enclosed by a pair of braces. Let us discuss each of these parts of the program.

6.10.1 Preprocessor directives

A C++ program starts with pre-processor directives. Preprocessors are the compiler directive statements which give instruction to the compiler to process the information provided before actual compilation starts. Preprocessor directives are lines included in the code that are not program statements. These lines always start with a # (hash) symbol. The pre-processor directive `#include` is used to link the header files available in the C++ library by which the facilities required in the program can be obtained. No semicolon (;) is needed at the end of such lines. Separate `#include` statements should be used for different header files. There are some other pre-processor directives such as `#define`, `#undef`, etc.

6.10.2 Header files

Header files contain the information about functions, objects and predefined derived data types and they are available along with compiler. There are a number of such files to support C++ programs and they are kept in the standard library. Whichever program requires the support of any of these resources, the concerned header file is to be included. For example, if we want to use the predefined objects `cin` and `cout`, we have to use the following statement at the beginning of the program.

```
#include <iostream>
```

The header file `iostream` contains the information about the objects `cin` and `cout`. Even though header files have the extension `.h`, it should not be specified for GCC. But the extension is essential for some other compilers like Turbo C++ IDE.

6.10.3 Concept of namespace

A program cannot have the same name for more than one identifier (variables or functions) in the same scope. For example, in our home two or more persons (or even living beings) will not have the same name. If there are, it will surely make conflicts in the identity within the home. So, within the scope of our home, a name should be unique. But our neighbouring home may have a person (or any living being) with the same name as that of one of us. It will not make any confusion of identity within the respective scopes. But an outsider cannot access a particular person by simply using the name; but the house name is also to be mentioned.

The concept of namespace is similar to a house name. Different identifiers are associated to a particular namespace. It is actually a group name in which each item is unique in its name. User is allowed to create own namespaces for variables and functions. We can use an identifier to give name to a namespace. The keyword `using` technically tells the compiler about a namespace where it should search for the elements used in the program. In C++, `std` is an abbreviation of 'standard' and it is the standard namespace in which `cout`, `cin` and a lot of other objects are defined. So, when we want to use them in a program, we need to follow the format `std::cout` and `std::cin`. This kind of explicit referencing can be avoided with the statement `using namespace std;` in the program. In such a case, the compiler searches this namespace for the elements `cin`, `cout`, `endl`, etc. So whenever the computer comes across `cin`, `cout`, `endl` or anything of that matter in the program, it will read it as `std::cout`, `std::cin` or `std::endl`.

The statement `using namespace std;` doesn't really add a function, it is the `#include <iostream>` that "loads" `cin`, `cout`, `endl` and all the like.

6.10.4 The `main()` function

Every C++ program consists of a function named `main()`. The execution starts at `main()` and ends within `main()`. If we use any other function in the program, it is called (or invoked) from `main()`. Usually a data type precedes the `main()` and in GCC, it should be `int`.

The function header `main()` is followed by its body, which is a set of one or more statements within a pair of braces `{ }`. This structure is known as the definition of the `main()` function. Each statement is delimited by a semicolon `;`. The statements may be executable and non-executable. The executable statements represent instructions to be carried out by the computer. The non-executable statements are intended for compiler or programmer. They are informative statements. The last statement in the body of `main()` is `return 0;`. Even though we do not use this statement, it will not make any error. Its relevance will be discussed in Chapter 10.

C++ is a free form language in the sense that it is not necessary to write each statement in new lines. Also a single statement can take more than one line.

6.10.5 A sample program

Let us look at a complete program and familiarise ourselves with its features, in detail. This program on execution will display a text on the screen.

```
#include <iostream>
using namespace std;
int main()
{
    cout<<"Hello, Welcome to C++";
    return 0;
}
```

The program has seven lines as detailed below:

Line 1: The preprocessor directive `#include` is used to link the header file `iostream` with the program.

Line 2: The `using namespace` statement makes available the identifier `cout` in the program.

Line 3: The header of the essential function for a C++ program, i.e., `int main()`.

Line 4: An opening brace `{` that marks the beginning of the instruction set (program).

Line 5: An output statement, which will be executed when we run the program, to display the text "Hello, Welcome to C++" on the monitor. The header file `iostream` is included in this program to use `cout` in this statement.

Line 6: The `return` statement stops the execution of the `main()` function. This statement is optional as far as `main()` is concerned.

Line 7: A closing brace `}` that marks the end of the program.

6.11 Guidelines for coding

A source code looks good when the coding is legible, logic is communicative and errors if any are easily detectable. These features can be experienced if certain styles are followed while writing programs. Some guidelines are discussed in this section to write stylistic programs.

Use suitable naming convention for identifiers

Suppose we have to calculate the salary for an employee after deductions. We may code it as: $A = B - C;$

where A is the net salary, B the total salary and C total deduction. The variable names A, B and C do not reflect the quantities they denote. If the same instruction is expressed as follows, it would be better:

```
Net_salary = Gross_salary - Deduction;
```

The variable names used in this case help us to remember the quantity they possess. They readily reflect their purpose. These kinds of identifiers are called **mnemonic names**. The following points are to be remembered in the choice of names:

- Choose good mnemonic names for all variables, functions and procedures.
e.g. avg_hgt, Roll_No, emp_code, SumOfDigits, etc.
- Use standardized prefixes and suffixes for related variables.
e.g. num1, num2, num3 for three numbers
- Assign names to constants in the beginning of the program.
e.g. float PI = 3.14;

Use clear and simple expressions

Some people have a tendency to reduce the execution time by sacrificing simplicity. This should be avoided. Consider the following example. To find out the remainder after division of x by n, we can code as: $y = x - (x/n) * n;$

The same thing is achieved by a simpler and more elegant piece of code as shown below:

```
y = x % n;
```

So it is better to use simpler codes in programming to make the program more simple and clear.

Use comments wherever needed

Comments play a very important role as they provide internal documentation of a program. They are lines in code that are added to describe the program. They are ignored by the compiler. There are two ways to write comments in C++:

Single line comment: The characters `//` (two slashes) is used to write single line comments. The text appearing after `//` in a line is treated as a comment by the C++ compiler.

Multiline comments: Anything written within `/*` and `*/` is treated as comment so that the comment can take any number of lines.

But care should be taken that no relevant code of the program is included accidentally inside the comment. The following points are to be noted while commenting:

- Always insert prologues, the comments in the beginning of a program that summarises the purpose of the program.
- Comment each variable and constant declaration.
- Use comments to explain complex program steps.
- It is better to include comments while writing the program itself.
- Write short and clear comments.

Relevance of indentation

In computer programming, an indent style is a convention governing the indentation of blocks of code to convey the program's structure, for good visibility and better clarity. An indentation makes the statements clear and readable. It shows the levels of statements in the program.

The usage of these guidelines can be observed in the programs given in the next section.

Program gallery

Let us now write programs to solve some problems following the coding guidelines. The call-outs given are not part of the program. Program 6.1 displays a message.

Program 6.1: To display a message

```
/* This program displays the message
   "Smoking is injurious to health"
   on the monitor */
#include <iostream> // To use the cout object
using namespace std; // To access cout
int main() //program begins here
{
    //The following output statement displays a message
    cout << "Smoking is injurious to health";
    return 0;
} //end of the program
```

Multiline comment

Single line comment

Indentation

On executing Program 6.1, the output will be as follows:

```
Smoking is injurious to health
```

More illustrations on the usage of indentation can be seen in the examples given in Chapter 7.

Program 6.2 accepts two integer numbers from the user, finds its sum and displays the result.

Program 6.2: To find the sum of two integer numbers

```
#include <iostream>
using namespace std;
int main()
{ //Program begins
/* Two variables are declared to read user inputs and the
variable sum is declared to store the result
*/
    int num1, num2, sum;
    cout<<"Enter two numbers: "; //Prompt for input
    cin>>num1>>num2; //Cascading to get two numbers
    sum=num1+num2; //Assignment statement to find the sum
    cout<<"Sum of the entered numbers = "<<sum;
/* The result is displayed with proper message.
Cascading of output operator is utilized */
    return 0;
}
```

A sample output of Program 6.2 is given below:

```
Enter two numbers: 5 7
Sum of the entered numbers = 12
```

User inputs
separated by spaces

Let us consider another problem. A student is awarded with three scores obtained in three Continuous Evaluation (CE) activities. The maximum score of an activity is 20. Find the average score of the student.

Program 6.3: To find the average of three CE scores

```
#include <iostream>
using namespace std;
int main()
{
    int score_1, score_2, score_3;
    float avg;
    //Average of 3 numbers can be a floating point value
    cout << "Enter the three CE scores: ";
    cin >> score_1 >> score_2 >> score_3;
    avg = (score_1 + score_2 + score_3) / 3.0;
```

```

/* The result of addition will be an integer value. If 3
is written instead of 3.0, integer division will be
performed and will not get the correct result */
    cout << "Average CE score is: " << avg;
    return 0;
}

```

Program 6.3 gives the following output for the CE scores 17, 19 and 20.

```

Enter the three CE scores: 17    19    20
Average CE score is: 18.666666

```

The assignment statement to find the average value uses an expression to the right of assignment operator (=). This expression has two + operators and one / operator. The precedence of / over + is changed by using parentheses for addition. The operands for the addition operators are all int type data and hence the result will be an integer. When this integer result is divided by 3, the output will again be an integer. If it was so, the output of Program 6.3 would have been 18, which is not accurate. Hence floating point constant 3.0 is used as the second operand for / operator. It makes the integer numerator float by type promotion.

Suppose the radius of a circle 'r' is given and you are requested to compute its area and the perimeter. As you know, area of a circle is calculated using the formula πr^2 and perimeter by $2\pi r$, where $\pi = 3.14$. Program 6.4 solves this problem.

Program 6.4: To find the area and perimeter of a circle for a given radius

```

#include <iostream>
using namespace std;
int main()
{
    const float PI = 22.0/7; //Use of const access modifier
    float radius, area, perimeter;
    cout<<"Enter the radius of the circle: ";
    cin>>radius;
    area = PI * radius * radius;
    perimeter = 2 * PI * radius;
    cout<<"Area of the circle = "<<area<<"\n";
    cout<<"Perimeter of the circle = "<<perimeter;
    return 0;
}

```

Escape sequence '\n' prints a new line after displaying the value of Area

A sample output of Program 6.4 is as follows:

```
Enter the radius of the circle: 2.5
Area of the circle = 19.642857
Perimeter of the circle = 15.714285
```

The last two output statements of Program 6.4 displays both the results in separate lines. The escape sequence character '\n' brings the cursor to the new line before the last output statement gets executed.

Let us develop another program to find simple interest. As you know, principal amount, rate of interest and period are to be given as input to get the result.

Program 6.5: To find the simple interest

```
#include <iostream>
using namespace std;
int main()
{
    float p_Amount, n_Year, i_Rate, int_Amount;
    cout<<"Enter the principal amount in Rupees: ";
    cin>>p_Amount;
    cout<<"Enter the number of years for the deposit: ";
    cin>>n_Year;
    cout<<"Enter the rate of interest in percentage: ";
    cin>>i_Rate;
    int_Amount = p_Amount * n_Year * i_Rate /100;
    cout<<"Simple interest for the principal amount "
        <<p_Amount<<" Rupees for a period of "<<n_Year
        <<" years at the rate of interest "<<i_Rate
        <<" is "<<int_Amount<<" Rupees";
    return 0;
}
```

A sample output of Program 6.5 is given below:

```
Enter the principal amount in Rupees: 100
Enter the number of years for the deposit: 2
Enter the rate of interest in percentage: 10
Simple interest for the principal amount 100 Rupees for a
period of 2 years at the rate of interest 10 is 20 Rupees
```

The last statement in Program 6.5 is the output statement and it spans over four lines. Note that there is no semi colon at the end of each line and so it is considered a single statement. On execution of the program the result may be displayed in multiple lines depending on the size and resolution of the monitor of your computer.

Program 6.6 solves a temperature conversion problem. The temperature in degree celsius will be given as input and the output will be its equivalent in fahrenheit.

Program 6.6: To convert temperature from Celsius to Fahrenheit

```
#include <iostream>
using namespace std;
int main()
{
    float celsius, fahrenheit;
    cout<<"Enter the Temperature in Celsius: ";
    cin>>celsius;
    fahrenheit=1.8*celsius+32;
    cout<<celsius<<" Degree Celsius = "
        <<fahrenheit<<" Degree Fahrenheit";
    return 0;
}
```

Program 6.6 gives a sample output as follows:

```
Enter the Temperature in Celsius: 37
37 Degree Celsius = 98.599998 Degree Fahrenheit
```

We know that each character literal in C++ has a unique value called its ASCII code. These values are integers. Let us write a program to find the ASCII code of a given character.

Program 6.7: To find the ASCII value of a character

```
#include <iostream>
using namespace std;
int main()
{
    char ch;
    int asc;
    cout << "Enter the character: ";
    cin >> ch;
    asc = ch;
    cout << "ASCII value of "<<ch<<" = " << asc;
    return 0;
}
```

A sampler output of Program 6.7 is given below:

```
Enter the character: A
```

```
ASCII value of A = 65
```



Let us sum up

Data types are means to identify the type of data and associated operations handling it. Each data type has a specific size and a range of data. Data types are used to declare variables. Type modifiers help handling a higher range of data and are used with data types to declare variables. Different types of operators are available in C++ for various operations. When operators are combined with operands (data), expressions are formed. There are mainly three types of expressions - arithmetic, relational and logical. Type conversion methods are used to get desired results from arithmetic expressions. Statements are the smallest executable unit of a program. Variable declaration statements define the variables in the program and they will be allocated memory space. The executable statements like assignment statements, input statements, output statements, etc. help giving instructions to the computer. Some special operators like arithmetic assignment, increment, decrement, etc. make the expressions and statements compact and the execution faster. C++ program has a typical structure and it must be followed while writing programs. Stylistic guidelines shall be followed to make the program attractive and communicative among humans.



Learning outcomes

After the completion of this chapter the learner will be able to

- identify the various data types in C++.
- list and choose appropriate data type modifiers.
- choose appropriate variables.
- experiment with various operators.
- apply the various I/O operators.
- write various expressions and statements.
- identify the structure of a simple C++ program.
- identify the need for stylistic guidelines while writing a program.
- write simple programs using C++.



Lab activity

1. Write a program that asks the user to enter the weight in grams, and then display the equivalent in Kilograms.
2. Write a program to generate the following table

2013	100%
2012	99.9%
2011	95.5%
2010	90.81%
2009	85%

Use a single cout statement for output. (Hint: Make use of `\n` and `\t`)

4. Write a short program that asks for your height in Meter and Centimeter and converts it to feet and inches. (1 foot = 12 inches, 1 inch = 2.54 cm).
5. Write a program to compute simple interest and compound interest.
6. Write a program to : (i) print ASCII code for a given digit, (ii) print ASCII code for backspace. (Hint : Store escape sequence for backspace in an integer variable).
7. Write a program to accept a time in seconds and convert into hrs: mins: secs format. For example, if 3700 seconds is the input, the output should be 1hr: 1 min: 40 secs.

Sample questions

Very short answer type

1. What are data types? List all predefined data types in C++.
2. What is a constant?
3. What is dynamic initialisation of variables?
4. What is type casting?
5. Write the purpose of declaration statement?
6. Name the header file to be included to use cin and cout in programs?
7. What is the input operator ">>" and output operator "<<" called?
8. What will be the result of $a = 5/3$ if a is (i) float and (ii) int ?

9. What will be the value of $P = P++ + ++i$ where i is 22 and $P = 3$ initially?
10. Find the value given by the following expression if $j = 5$ initially.
 - (i) $(5*++j)\%6$
 - (ii) $(5*j++)\%6$
11. What will be the order of evaluation for following expressions?
 - (i) $i+5 >= j-6$
 - (ii) $s+10 < p-2+2*q$
12. What will be the result of the following if ans is 6 initially?
 - (i) `cout << ans = 8 ;`
 - (ii) `cout << ans == 8`

Short answer type

1. What is a variable? List the two values associated with it.
2. In how many ways can a variable be declared in C++?
3. Explain the impact of type modifiers of C++ in variable declaration.
5. What is the role of the keyword 'const'?
6. Explain how prefix form of increment operation differs from postfix form.
8. Write down the operation performed by sizeof operator.
9. Explain the two methods of type conversions.
10. What would happen if `main()` is not present in a program?
11. Identify the errors in the following code segments:
 - (a)


```
int main()
{ cout << "Enter two numbers"
  cin >> num >> auto
  float area = Length * breadth ; }
```
 - (b)


```
#include <iostream>
using namespace std
void Main()
{ int a, b
  cin <<a <<b
  max=(a > b) a:b
  cout>max
}
```
12. Find out the errors, if any, in the following ++ statements:
 - (i) `cout << "a=" a;`
 - (v) `cin >> "\n" >> y ;`
 - (ii) `m=5, n=12; 015`
 - (vi) `cout >> \n "abc"`

- (iii) `cout << "x" ; <<x;` (vii) `a = b + c`
(iv) `cin >> y` (viii) `break = x`

13. What is the role of relational operators? Distinguish between `==` and `=`.
14. Comments are useful to enhance readability and understandability of a program. Justify this statement with examples.

Long answer type

1. Explain the operators of C++ in detail.
2. Explain the different types of expressions in C++ and the methods of type conversions in detail.
3. Write the working of arithmetic assignment operator? Explain all arithmetic assignment operators with the help of examples.