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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

(In the Name of Allah, the Most Compassionate, the Most Merciful.)

# COMPUTER SCIENCE AND ENTREPRENEURSHIP

# 9

Based on Revised National Curriculum of Pakistan 2023

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# UNIT 1

## Introduction to Systems

### Student Learning Outcomes

#### Understand System Theory:

- Define and describe general system theory, its types, objectives, components, and interactions.
- Explain the concept of a system, including objectives, components, and communication.
- Describe what constitutes a system and its role in various domains.
- Explain the importance of system objectives and common objectives such as processing information, supporting applications, and achieving specific goals.
- Understand the role and importance of system components and their interactions.
- Explain the significance of interactions among various systems.
- Differentiate between natural and artificial systems.
- Categorize and describe various types of natural and artificial systems, their objectives, components, and interactions.
- Provide examples of natural systems, including physical, chemical, biological and psychological systems along with their characteristics.
- Provide examples and functions of artificial systems, including knowledge systems, engineering systems, and social systems.
- Analyze systems to identify their objectives, components, and interactions.
- Compare and contrast different types of systems, highlighting variations in objectives, components, and interactions.
- Conduct research on specific system types and present findings effectively.
- Create diagrams or models to visually represent the structure and interactions of systems.
- Assess the role and importance of system objectives in real-world applications.
- Demonstrate understanding of how systems apply to different fields and serve specific functions.

#### Computing Systems

- Define and describe a computer as a system, including its objectives, architecture, components, and interactions.
- Understand the primary objectives of a computing system, including processing data, executing instructions, and providing a user interface.
- Recognize the role and importance of computer system components and their interactions.
- Identify necessary and auxiliary components of a computer system.
- Identify different types of computing systems, such as computers, software, computer networks, and the Internet.
- Understand the Von Neumann architecture and its core components: CPU, motherboard, memory, storage devices, input/output ports, and devices.
- Explain the relationship between the CPU, memory, and storage, and how data flows within a system.
- Describe how components within a computer system interact to execute tasks, such as how the CPU fetches, decodes, and executes instructions stored in memory.
- Differentiate between the roles of hardware and software in a computer system.
- Define and describe Computing system and its types including Computer, Software, Network and the Internet.
- Describe the main functions of system software, such as operating systems, and application software.



## Introduction

This chapter provides an overview of the theory of systems, introducing fundamental concepts and exploring various types of systems. It begins by defining what a system is, discussing its basic components, objectives, environment, and methods of communication. The chapter then differentiates between natural and artificial systems, explaining how they function and their purposes. The relationship between systems and different branches of science is also explored, including natural science, design science, and computer science. The chapter then shifts back to discussing computers as systems, explaining their goals, parts, and how these parts connect with each other and their surroundings. It provides a detailed look at the Von Neumann computer architecture, exploring its components, how it works, its unique features, as well as its strengths and weaknesses. The chapter also covers different types of computing systems, such as computers, software, networks, and the Internet, clearly explaining their roles and purposes. At the end of this chapter, the reader will be in a better position to understudy systems, their classification, and relevance in natural and man-made systems to aid future learning and utilization.

### 1.1 Theory of Systems

The idea of a system is useful to explain both the external reality as well as the internal one. An Information System is simply an organized set of components that are coordinated to perform a designated function. All the components of the system are in some way related to each other and the functioning of the other components enhances the operation of the system.

Let us consider a simple example, such as a car, depicted in Figure 1. 1: it is made up of an engine, wheels, brakes, and other related items. Every part plays a unique task, but collectively they are responsible for making the car move. Likewise, every computer, organism, machine, or device has components that work together to achieve an outcome.

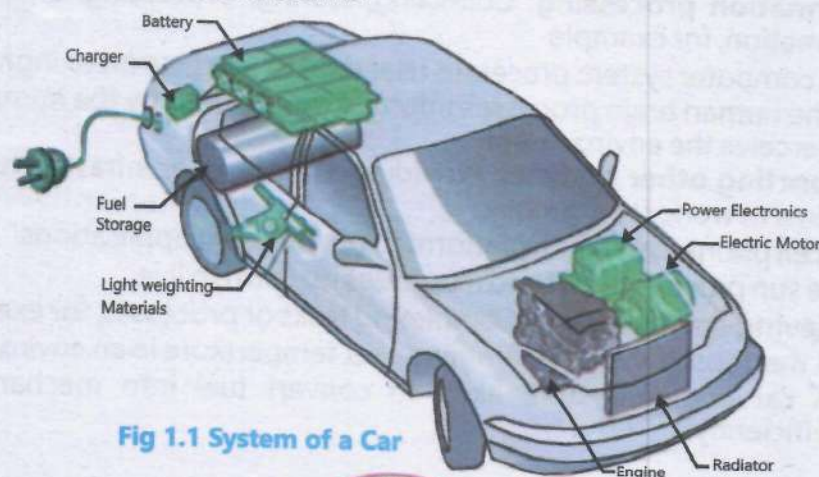


Fig 1.1 System of a Car



## Systems Theory:

A branch of a science that deals with complicated structures in living organisms, that relate the human with society and the science is known as Systems Theory. It gives a way of interpreting the existing world with different varied perspectives, how the different systems and sub-systems operate, how they are integrated, how they grow and how they change with time.

Systems can be observed at all levels of existence, starting with the levels of nature, and going all the way up to levels of systems designed by humans. These can be physical objects-such as a car; processes, such as the university's admission process; or abstract objects such as a mathematical formula. Thinking about how systems operate helps us better understand how they need to be developed and nurtured across different discipline like computing, biology, engineering, and social science. In this section, basic concepts will be introduced to emphasize fundamental concepts and principles.

### 1.1.1 Basic Concepts of Systems

A system is described by its objectives components, communication among components and environment in which it works. The components of a system communicate with each other to achieve the system's objective in an environment. Systems can be simple, like a thermostat, or complex, like the human body or a computer network.

#### 1.1.1.1 Objective

Every system has a purpose or goal that it wishes to fulfil. Analyzing a system's operation requires understanding its aim. This insight improves the efficiency and efficacy of the present system. A transport system aims to transfer people and products securely and effectively between locations. A computer system's principal goal is to process data and provide useful information to users.

#### Types of System Objectives

Systems can have different objectives depending on their nature and purpose. Common objectives include:

1. **Information processing:** Collecting, storing, processing, and distributing information, for example
  - o A computer system processes user data to produce meaningful outputs.
  - o The human brain processes information received by the human senses to perceive the environment.
2. **Supporting other systems:** Providing a platform or infrastructure for other systems to work, for example:
  - o A cell phone provides a platform to run different applications.
  - o The sun provides energy to all species on Earth to live.
3. **Achieving specific goals:** Completing tasks or processes, for example:
  - o A thermostat system maintains a set temperature in an environment.
  - o A car engine system aims to convert fuel into mechanical energy efficiently.





**Brain: Information processing**



**Cell Phone: Supporting other systems**



**Thermostat: Achieving specific goals**

**Fig. 1.2 Types of System Objectives**

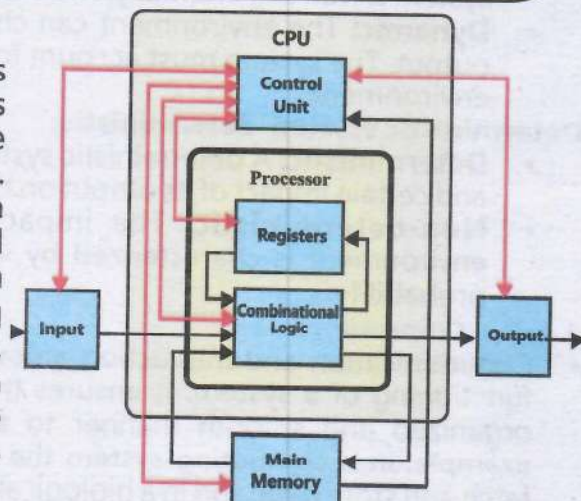
### Human Brain System

1. Your brain is an incredible example of a communication network. Neurons send signals to each other, allowing you to think, move, and experience emotions. This complex communication is what makes our brains so powerful.
2. The brain produces around 20 watts of electrical energy, sufficient to operate a low-wattage LED light bulb. Presented here is the brain's remarkable efficacy as an electrical system.
3. The information traveling through your brain moves at about 268 miles per hour, which is faster than a Formula 1 race car.
4. Your brain, as a biological system, has around 86 billion neurons. If each neuron was a person, it is like the population of about ten Earth all interacting simultaneously!
5. The human brain can perform about  $10^{16}$  (10 quadrillion) operations per second, making it one of the most powerful and efficient biological systems in existence.

### Tidbits

#### 1.1.1.2 Components

Components are the building blocks of any system. Each component plays a specific role and contributes to the overall functionality of the system. Understanding the role of each component of the system is essential to understand how the entire system works. This helps in identifying problems, improving performance, and refining system design. Smooth and proper working of these components together ensures the system meets its objectives.





## Human Body and its DNA System

## Tidbits

1. Consider your body as a very sophisticated and effective system. It is a remarkable system comprising subsystems such as the circulatory system, neurological system, and digestive system. The cardiovascular system circulates blood. The respiratory system supplies oxygen, and the cerebral system processes information. Individually, each has a distinct function yet collaborates to ensure our survival and well-being.
2. DNA is like a blueprint for life. It's a system that contains all the instructions for an organism to grow, develop, and reproduce, passed down from generation to generation. Each cell in our body reads this blueprint to know what to do. When all the DNA in a single human cell is extended, it measures about two meters in length. The total long of the DNA in your body extends to the Sun and back more than six hundred times.

### 1.1.1.3 Environment

The environment of a system includes everything external to the system that interacts with it. It consists of all external factors that affect the system's operation. Understanding the environment of a system is important as it influences the system's performance and behavior by providing inputs and receiving outputs. Intelligent systems adjust to changes in their environment to continue their functionality. There are several properties of a system's environment that affect system design and its functionality. Two of these properties are described as follows:

#### Static vs. Dynamic:

- **Static:** The environment remains unchanged unless the system provides an output. There are no changes occurring in the environment while the system is working internally.
- **Dynamic:** The environment can change independently of the system's output. The system must account for changes that occur over time in the environment.

#### Deterministic vs. Non-deterministic:

- **Deterministic:** A deterministic system is characterized by its fully known and certain impact of its output on the environment.
- **Non-deterministic:** The impact of the system's output on the environment is characterized by inherent uncertainty, randomness, or probability.

### 1.1.1.4 Communication

- Communication and interaction among system components is key to the functioning of a system. It ensures that components work together in an organized and smooth manner to achieve the system's objectives. For example, in a computing system the CPU communicates with memory to fetch and store data, and in a biological system brain sends signals to muscles to initiate movement.



## System's Interaction with the Environment

Systems constantly interact with their environment through inputs and outputs. For example, a weather monitoring system receives data from environment sensors and provides the current status of the weather and future forecasts to users. In a computing system, computers interact and communicate with peripheral devices like printers and scanners, and in a biological system animals interact with plants and other animals, forming a food chain.

### Activity: Classroom Discussion, Brainstorming, and System Mapping

**Objective:** To introduce the concept of systems and understand how different components interact within a system.

**Required Material:** Poster boards, markers, sticky notes, chart paper, drawing tools.

**Activity Type:** Group

**Activity Tasks Detail:** Start with a discussion where the teacher introduces the concept of systems using examples like cars and schools. Students will contribute their examples and ideas. Next perform a brainstorming session, where students will work in groups to identify and list the systems they interact with daily. They will then create a system map on poster boards, labeling the components and their interactions. Finally, during a gallery walk, each group will present their system map, followed by a feedback session where the teacher provides feedback and answers questions.

**Output:** Each group will produce a system map poster illustrating their chosen system, and students will enhance their presentation and explanation skills.

### Activity: Design a Simple System

**Objective:** To apply the principles of system design and understand the process of creating a functional system.

**Required Material:** Computers or tablets with diagramming software (e.g., Lucidchart), paper, pencils, markers.

**Activity Type:** Pair

**Activity Tasks Detail:** Begin with an introduction where the teacher presents an example of a simple system. Students will then work in pairs to define the objective of their chosen system, list its components, describe their interactions, and outline the system's environment. The pairs will use diagramming software to create a system prototype or diagram. Finally, they will present their designs to the class in a review and feedback session.

**Output:** Each pair will produce a system prototype or diagram and receive feedback to refine their design ideas.

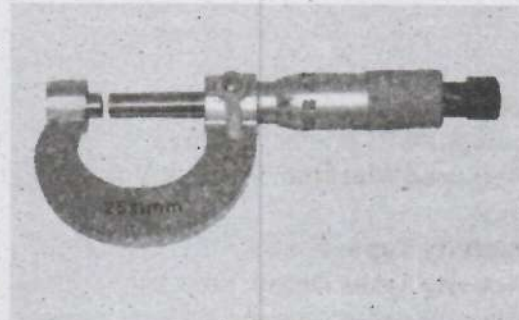


## 1.2 Types of Systems

Systems can be broadly categorized into two types, namely natural and artificial systems. Understanding the differences and similarities between these types helps us apply system theory across various fields. Natural systems are naturally built and occur in nature without human intervention. While artificial systems are created by humans to fulfill specific needs or purposes.



Galaxy a Natural System



Screw gauge an Artificial System

Fig. 1.4 Examples of Systems

### 1.2.1 Natural Systems

Natural systems are those that exist in nature and operate independently of human involvement. They are governed by natural laws and processes. Natural systems are of various forms and sizes, from very tiny objects like atoms and cells in our body to very huge like forests, oceans and the cosmos. Following are examples of some natural systems that exist in nature.

#### 1.2.1.1 Physical Systems

Physical systems are composed of physical components and governed by the laws of physics. They include things ranging from sub atomic particles, atoms, to planets, stars, galaxies, and cosmos. Physical systems, like any kind of matter, emerge from the interactions of electrons, protons, neutrons and sub-atomic particles which are governed by electric and atomic forces. For example hydrogen gas (H) is formed when an electron, proton, and neutron combine, following the rules of physics and natural forces.

#### 1.2.1.2 Chemical Systems

Chemical systems involve substances and their interactions, transformations, and reactions. They are governed by the laws of chemistry. Chemical systems emerge from physical systems when atoms and molecules interact and bond according to chemical principles, forming new substances. For example, a chemical system like water (H<sub>2</sub>O) is formed when hydrogen atoms bond with oxygen atoms, following chemical rules and reactions.

#### 1.2.1.3 Biological Systems

Biological systems consist of living organisms and their interactions. They are governed by biological processes such as growth, reproduction, and metabolism. Biological systems emerge from chemical systems when molecules



interact in complex ways to form living cells, which then organize into tissues, organs, and organisms.

#### 1.2.1.4 Psychological Systems

Psychological systems involve the mind and behavior. They include thoughts, emotions, and mental processes, governed by the principles of Psychology. Psychological systems emerge from biological systems when the brain's physical and chemical processes give rise to thoughts, emotions, and behaviors, which are influenced by an individual's experiences and environment.

##### Activity: Interactive Simulation

The purpose of this activity is with the aim of understanding how variability affects the system of interest.

**Materials Needed:** Computers or tablets with internet access and online simulation tools (like an ecosystem simulator).

**Activity Tasks Detail:** Individual or Group Assignments The teacher will begin by explaining what system dynamics entail as well as provide an overview on how the simulation will be implemented. Students will then work with the simulation tool, manipulating different variables and analyzing how the system reacts. Using an S-curve to review their results, the students will be reflecting on how changes impact the entire system during the discussion. The teacher will emphasize that all these parts are integrated and balanced, and the students will follow this aspect during their conversation.

**Outcome:** They produce detailed observation notes as well as better insights into system dynamics and balance.

#### 1.2.2 Artificial Systems

Artificial systems are created and developed by people so that they may fulfill certain functions or address certain issues. These systems can be as small as a wheel or as large as the United Nations. Each system is designed very deliberately to perform the task, improve the efficiency of the processes, and provide solutions to various issues in different sectors.

Artificial systems are a vital part of the contemporary society because they reinforce productivity, solve complex problems, and improve people's well-being. These are systems such as knowledge management systems, engineering achievement systems and indeed social systems which are the framework of success of human civilization. There are different types of artificial systems, some of which are described below:

##### 1.2.2.1 Knowledge Systems

A knowledge system is unique because it is developed to capture, process, facilitate, store, retrieve and manage information. Such systems facilitate in managing and utilizing the resources of knowledge effectively for the purpose of decision-making, learning and problem-solving.



1. **Mathematics:** Mathematics is a field of knowledge, which is studied to focus problems connected to numbers, their amounts, forms, structures, and patterns.
2. **Logic:** Logic is a theoretical model consisting of concepts and strategies on identifying and assessing rationale. That is why it is a basis of all logical thinking processes and practice of critical analysis.
3. **Databases:** A database system can best be described as software for managing data, particularly to enable easy retrieval, management, and updating of data. Some of the examples are relational database management system like MySQL while others are NoSQL database management system like MongoDB.
4. **Information Management Systems:** These are specific applications developed with the purpose of capturing, archiving, organizing, and disseminating data.

#### 1.2.2.2 Engineering Systems

Products developed by engineers are complex frameworks or devices that apply engineering concepts to perform certain tasks or solve technical challenges. These are some examples of how engineers of various types develop systems according to their own special knowledge and perspective, given to them through their original visions and approaches.

1. **Civil Engineering Systems:** Concentration on developments such as constructing houses, roads, bridges and even maintaining these structures. For instance, a structure used to provide a passage over water, valleys or roads is termed a bridge.
2. **Mechanical Engineering Systems:** Engage in planning and creating devices that make utilization of forces from outside to accomplish work. For instance, a robotic arm applied in assembly line for packaging of products in factories.
3. **Chemical Engineering Systems:** Focuses on converting raw materials into useful products through chemical processes, considering internal molecular interactions. For example, a water treatment plant that purifies water using chemical processes like coagulation and filtration.
4. **Electrical Engineering Systems:** Involves the study and application of electricity, electronics, and electromagnetism to develop electrical systems. For example a home automation system that controls lighting, heating, and security using a smartphone app. This system uses electric signals and power to operate various home appliances and systems remotely.
5. **Software Engineering Systems:** Is the process of designing, developing, and maintaining software to perform certain tasks eradicating errors. For instance, an online tool assisting a library in tracking books, users as well as stocks in their possession.



### Artificial Engineering System

- The Metro Train System in Lahore is an artificial system created for efficient transportation. The railway system consists of tracks, trains, stations, and control systems that transport people between locations.
- The first electric traffic lights were built in Cleveland, Ohio, in 1914. Modern traffic systems use smart sensors and AI to enhance safety and flow.
- AI systems, such as Siri and Alexa, can recognize and respond to human speech. These examples demonstrate how computer systems may interact with humans naturally through complicated algorithms and data processing.
- Virtual Reality (VR): Immersive digital worlds enable exploration and interaction as if you were physically present. This technology has several applications, including gaming, teaching, and astronaut training.

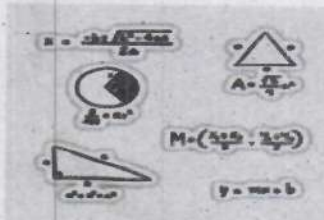
### 1.2.2.3 Social Systems

Social systems refer to structured frameworks established by individuals to effectively handle social interactions, organizational governance, and communal endeavors. The basic goal of these systems is to maintain order, provide services, and facilitate social connections.

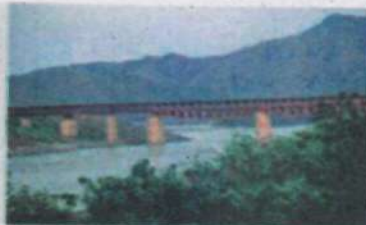
**1. Academic institutions:** are entities that provide educational services to students. Schools, colleges, and universities are examples of educational institutions that provide instruction via the use of administrative, teaching, and support staff.

**2. Governments:** Organizational institutions that wield authority and control over a community or country. Examples include democratic systems, where representatives are elected and authoritarian regimes, where power is centralized.

**3. Organizations:** are entities formed to achieve specific goals and are often structured hierarchically with well-defined roles and responsibilities. Examples include corporations like Apple and non-profit organizations such as the Edhi Foundation.



Mathematics a Knowledge System



Attock Bridge an Engineering System



Punjab University a Social System

**Fig. 1.5 Types of Artificial Systems**



#### Activity: Simulation Game

**Objective:** To experience managing a system and making decisions to keep it functional.

**Required Material:** Computers or tablets with internet access, city simulation game (e.g., SimCity).

**Activity Type:** Pair (Group of two students)

**Activity Tasks Detail:** Begin with an introduction to the simulation game, explaining its objectives and mechanics. Students will then play the game in pairs, making strategic decisions to manage their city. After gameplay, a debriefing session will allow students to discuss their experiences, challenges, and strategies. The teacher will link these experiences to system management concepts discussed in class.

**Output:** Hands-on gameplay experience and reflection on system management challenges and strategies.

### 1.3 System and Science

Knowledge is our understanding of various systems in the universe around and within us. Science is a systematic way to validate this understanding. Science can be divided into two main types: natural science and design science. Both natural and design sciences study systems, but they approach them differently. In natural science, scientists study existing natural systems to understand their workings. While in design science, scientists create new systems (artifacts) to solve problems or achieve specific goals. Each type of science addresses different systems and questions, and therefore follows different scientific methods.

#### 1.3.1 Natural Science

Natural science is meant to uncover the objectivity and functionality of natural systems in the natural world. Its nature is descriptive, meaning that the scientists seek to understand and describe natural phenomena. To achieve this, natural scientists follow the empirical cycle of natural science, as shown in Figure 1.6.



Fig. 1.6 Empirical Cycle of Natural Science



### 1.3.2 Design Science

- Design Science is focused on designing and creating artifacts (tools, systems, methods) to achieve specific goals. The nature of design science is prescriptive, meaning that it aims to prescribe and create artificial systems. To achieve this design science researchers follow the regulative cycle.

#### Examples

- **Natural Science:** Studying the ecosystem of a forest to understand how different species interact (descriptive).
- **Design Science:** Developing a new software system to manage forest data and improve conservation efforts (prescriptive).

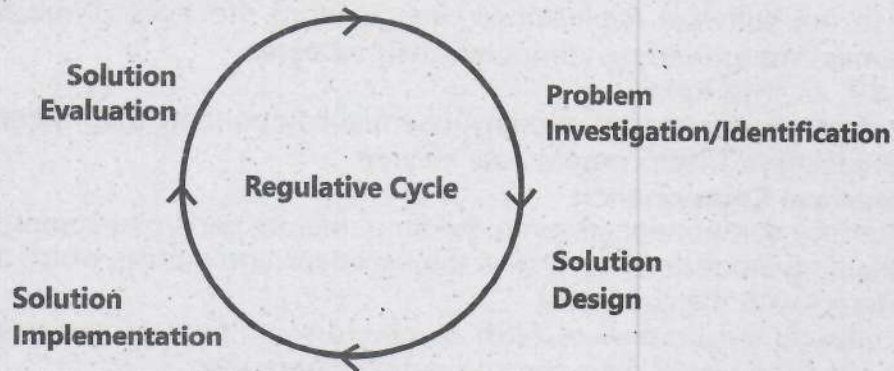


Fig. 1.7 Regulative Cycle of Design Science

### 1.3.3 Computer Science

Computer science is the study of how computers work, including at what they can do and their limitations. To understand computer science, we use methods of both design science and natural science.

#### 1.3.3.1 Natural Science of Computer Science

Natural science of computer science focuses on finding the basic rules that control how computer systems work. This involves the study of various algorithms and their characteristics.

- **Study of Algorithms:** Researchers analyze existing algorithms to understand their efficiency and limitations. For example, studying different sorting algorithms and their characteristics which arrange given data in an order, like QuickSort or MergeSort. To understand their speed and how they perform with different kinds of data.

#### 1.3.3.2 Design Science of Computer Science

Design science of computers focuses on creating and improving computer tools and systems to make them work better.

- **Development of New Software Tools:** Researchers create new tools or applications to solve specific problems. For example: Designing a new programming language that makes it easier for developers to write secure computer programs.



- **Improvement of Computer Systems:** Researchers work on enhancing existing systems to perform better. For example, creating a more efficient database management system that can handle larger amounts of data faster and with fewer errors.

#### 1.4 Computer as a System

A computer is a complex system designed to process data and perform tasks according to a set of instructions.

##### 1.4.1 Objective

The main objective of a computer is to perform computations, process data, and execute different tasks efficiently. For example, a personal computer's objective is to run software applications such as word processors, web browsers, and games through various computational processes.

##### 1.4.2 Components

A computer composed of many essential components that operate in conjunction. These components include:

###### **Interface Components:**

Interface components refer to the fundamental parts of a computer system, including input devices such as the keyboard and mouse, which allow users to interact with the computer.

Computer output devices, such as monitors and printers, are used to present or generate results from the computer's operations.

###### **Processing Components:**

- The processing components of a computer consist of the CPU, which acts as the Central Processing Unit responsible for computations and executing command.
- Random Access Memory (RAM) is a transient storage that stores data and instructions for the CPU, whereas Storage (Hard Drive or SSD) is a permanent storage for data and software needed for future processing.
- The operating system is responsible for receiving information from interface components and determining the appropriate actions to take.
- Application software refers to programs that are executed by the operating system when required to perform one or more specified tasks.

###### **Communication Components:**

Communication components in a computer refer to the physical elements that provide communication between different components of the computer.

- In a computer, the motherboard serves as the primary circuit board that interconnects all components by using cables and circuits.
- A system bus is a collection of electrically conductive cables that transmit data between the CPU and all other interconnected components. There are three distinct types of buses: data bus, address bus, and control bus. These buses provide the flow of data, the address of data or instructions, and control signals from the CPU to other components concurrently.





Fig. 1.8 Computer System and its components

### 1.4.3 Interactions among Components

The components of a computer interact with each other to perform tasks. For example when you open a file using your mouse or keyboard, several components of your computer interact seamlessly to make this action happen. Here's a step-by-step explanation of the process:

1. User Action or Input. You double-click on a file icon using your mouse or press a key combination to open a file. For example you double-click on a document named "report.docx" on your desktop.
2. Input Device. The mouse or keyboard sends a signal to the computer indicating that you want to open the file. For example, the mouse sends sensory input to the computer's operating system through the USB connection.

#### Activity: The Journey of Data

**Objectives:** Students will discover how computer components work together to process and display data.

**Required Material:** Markers, index cards, and a flowchart template are required.

**Pair-based activity:** Tasks Begin with an introduction to data processing in computers. Students will work in pairs to create a flowchart illustrating the data stream from input to output. Each pair will present their flowcharts and participate in a class discussion to highlight key points.

**Output:** Improved presentation and debating skills, as well as thorough flowcharts depicting the data path.



#### 1.4.4 Environment

The computer system environment includes any external devices that interact with the computer. For example:

- **Power Supply:** Provides electrical power to allow the computer to work.
- **Network:** Connects the computer to other systems and the Internet.
- **Peripherals:** Include printers, scanners, and external discs that expand the computer's capabilities.

#### 1.4.5 Interaction with the Environment

A computer interacts with its environment to perform its functions. For examples:

- **User Input:** A user types on the keyboard, and the computer processes the input to display text on the screen.
- **Network Communication:** The computer sends and receives data over the internet to browse websites or download files.
- **Power Supply:** The computer relies on a stable power supply to function correctly.

#### Activity: Exploring Computer Components

**Objective:** Students will learn about the different components of a computer and their functions.

**Required Material:** Physical computer parts (CPU, RAM, etc.), diagrams of computer systems, worksheets for labeling and note-taking.

**Activity Type:** Group (Small groups of 3-4 students)

**Activity Tasks Detail:** The teacher will start with an overview of key computer components. Students will then work in small groups identifying and labeling computer parts using worksheets. Groups will present their findings in a session, followed by a Q&A where the teacher clarifies any misunderstandings.

**Output:** Labeled worksheets, enhanced presentation skills, and a deeper understanding of computer components.

### 1.5 The Architecture of von Neumann Computers

The Von Neumann architecture is a computer paradigm that delineates a system in which the hardware of the computer has four primary components: the memory, the Central Processing Unit (CPU), input mechanisms, and output mechanisms. This model is called the John von Neumann model, the Neumann model named in honor of the mathematician and physicist who contributed to its development during the 1940s.

#### 1.5.1 Components

Now we will look at brief overview of the key parts that constitute the architecture of the von Neumann computer.



1. **Memory:** Contains both input data and the instructions (program) required for CPU processing. For instance, consider the RAM of your computer: when a program starts it is loaded into RAM to enable faster execution compared to when it runs from the hard disk.
2. **Central Processing Unit (CPU):** Performs addition and subtraction, and executes commands provided by the memory. The system has two main components: the Arithmetic Logic Unit (ALU) and the Control Unit (CU). The Arithmetic Logic Unit (ALU) performs mathematical computations and logical operations.  
A Control Unit (CU) is a peripheral that governs the activities of the CPU by instructing the ALU and memory to execute tasks according to the program instructions. It ensures the proper and timely execution of duties by all the other components.  
When doing the calculation  $2 + 2$  on a calculator application, the Arithmetic Logic Unit (ALU) handles the numerical values while the control Unit (CU) supervises the whole procedure.
3. **Input Devices:** Enable users to input data and instructions into the computer system.  
Illustrative examples include keyboard, mouse, and microphone. Entering text on the keyboard transmits data to the CPU for subsequent processing.
4. **Output Devices:** Present or communicate the outcomes of the tasks executed by the computer.  
Consider, for instance, a monitor and printer. Upon completion of data processing, the CPU transmits the outcome to the monitor for visual display.  
A system bus is a communication mechanism that facilitates the movement of data between components inside a computational system. It comprises:  
Data Bus: Transports data.  
Address Bus: Maintains data destination information.  
Control Bus: Transports control electrical signals.

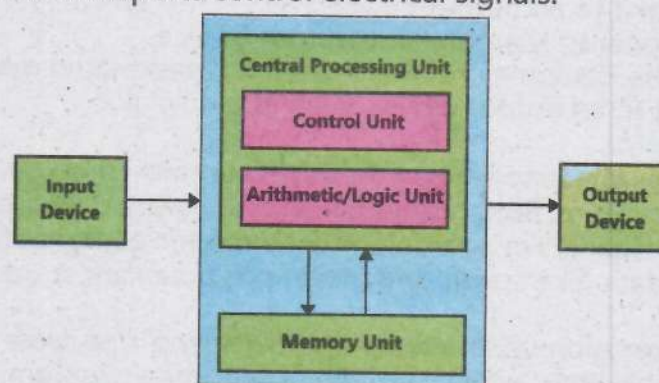


Fig. 1.9 Von Neumann computer Architecture



### 1.5.2 Working

The Von Neumann architecture encompasses three essential stages for a CPU to carry out instructions, namely retrieval, interpretation, execution, and storage. To demonstrate this procedure, we will use the example two-digit addition with a basic calculator application.

- **Fetching:**

Description: The central processing unit retrieves an instruction from the computer's memory. This instruction specifies the operation to be executed by the CPU.

Hardware Components: Memory, CPU (Program Counter (PC), Instruction Register (IR)).

Specification: The Program Counter (PC) stores the memory address of the subsequent instruction. Once the address is stored in memory, the instruction located at that location is retrieved and placed into the Instruction Register (IR).

- **Decoding:**

In order to determine the necessary action, the Control Unit (CU) decodes the instruction.

Comprising Components: Control Unit (CU).

Detail: The control unit (CU) decodes the opcode (operation code) of the instruction and determines the required procedures and data.

- **Execution:**

Description: The CPU processes the instruction. When the instruction involves a computation, it is executed by the Arithmetic Logic Unit (ALU). Any task that requires transferring data between several locations is managed by the CU.

Involved Components: ALU, CU.

Detail: The Arithmetic and Logic Unit (ALU) carries out mathematical and logical calculations, while the Control Unit (CU) handles data transmission activities.

- **Storing:** Description: The outcome of the computation is either returned to memory or sent to an output device.

Involved Components: Memory and Output Device.

Specification: The outcome is either stored in a designated memory location or sent to an output device, such as a display.

### 1.5.3 Characteristics

Following are the key characteristics of the Von Neumann computer architecture

1. **Single Memory Store:** Both program instructions and data are stored in the same memory space. For example in a computer game, both the game's code and the data (like scores and player positions) are stored in the same RAM.
2. **Sequential Execution:** Instructions are processed one after another in a sequence. For example, when your computer runs a program, it follows the steps one by one in the order they are written.



3. **Stored Program Concept:** Programs are stored in memory and can be changed by the computer. For example, when you update a software program, the new instructions replace the old ones in memory.

#### 1.5.4 Advantages and Disadvantages

The advantages and disadvantages of Von Neumann computer architecture are discussed here.

##### Advantages:

- **Simplified Design:** By combining instructions and data into a single memory area, architecture is simplified.
- **Flexibility:** Programs can be easily changed by changing memory contents.

##### Disadvantages:

- **The Von Neumann bottleneck** occurs when a single memory area limits the CPU's ability to retrieve instructions and data quickly.
- **Security Risks:** Having data and instructions stored in the same area poses a problem where one program can alter another's instructions in a manner that is security risk. The Von Neumann architecture is a key important aspect of the design and structure of many computers, serving as a central model on how they operate. It is like a recipe fed into the computer, which follows it exactly ensuring that both data and instructions are properly processed. However, this model has been essential in the evolution of computing technology, despite its limitation.

#### 1.6 Computing Systems

A computer system is a structured set of hardware and software components specifically designed for data processing and the performance of various operations. These systems can range from simple technological tools, such as calculators used for performing mathematical calculations to complex network of linked computers. The basic task of a computer system is to execute program and manage data to achieve objectives such as problem solving, process control and communication aid. Hardware, software, and electric power are the three basic requisites that are needed to run a computing system and can be described in the following simple terms.

- **Hardware** of a computer system refers to the tangible components of the system. These include the Central Processing Unit (CPU), Random Access Memory (RAM), storage devices, and input and output devices.
- **Software** refers to a collection of instructions that dictate the requirements and actions that hardware must do. There exist two primary categories. System software and application software. System Software encompasses the Operating System (OS) and utility applications responsible for managing the computer's resources, such as Windows, macOS, and Linux distributions. Application software refers to software applications that are specifically developed to carry out certain functions for the user, such as word processors, web browsers, and games.



- **Electricity:** Electricity is the power source that enables the hardware components to function. Without electricity, the hardware components cannot function, and the computing system will not operate.

#### 1.6.1 Types of Computing Systems

Computing systems come in various types, some of these include the followings: 1. Computer, 2. Software Systems, 3. Computer Networks, and the 4. Internet.

Computers as a system has been discussed in previous sections, while the remaining two computing systems are described in this section.

#### 1.6.2 Computer Network as Systems

A computer network connects multiple computers and devices, enabling the efficient exchange of resources and information.

##### 1.6.2.1 Objectives

- **Resource Sharing:** Allow multiple users to share resources like files, printers, and internet access within an office or other settings.
- **Communication:** Enable efficient communication between devices and users.
- **Data Management:** Facilitate easy data management and collaboration.

##### 1.6.2.2 Components

###### • **Networking Hardware:**

**Routers:** Routers are devices that transmit data packets between their networks.

**Switches:** Switches connect devices in a network and facilitate communication.

**Network Cables:** A physical medium for data transfer.

###### • **Network Software:**

**Protocols:** Rules and conventions for data exchange such as TCP/IP.

**Network Operating Systems:** Software that manages network resources, such as Windows Server.

##### 1.6.2.3 Environment

A computer network operates in various environments, such as office buildings, data centers, or across the globe via the Internet. The environment influences network design, security, and performance.

##### 1.6.2.4 Types of Computer Networks

- **Local Area Network (LAN):** Connects computers in a specific area, such as a single building or school. For example, an office network that connects everyone. Employee PCs and printers.
- **Wide Area Network (WAN):** connects computers across larger geographic regions, such as cities, nations, and even continents. For example, consider the Internet which links computers worldwide.
- In summary, a computer network is an important system that enables resource sharing and communication among connected devices, using hardware and software components that work together seamlessly to perform various tasks.



### 1.6.3 Internet as a System

The Internet is a vast and complex system designed to connect multiple networks worldwide, including private, public, academic, business, and government networks. Its primary objective is to facilitate communication and data exchange between computers and users globally.

#### 1.6.3.1 Internet Protocols

- TCP/IP (Transmission Control Protocol/Internet Protocol): The core protocols that govern data transmission over the Internet.
- User Datagram Protocol (UDP): Faster but less reliable.
- File Transfer Protocol (FTP): Used for transferring files between computers.
- Post office Protocol (POP): Used for retrieving emails from server/network.

#### 1.6.3.2 Interaction among Components

The components of the Internet interact with each other to perform different tasks. For example when a user requests a web page through a web browser, several components of the Internet work together to display its contents on the user's screen.

#### 1.6.3.3 Environment

The Internet operates in a diverse and dynamic environment, connecting various types of networks across different locations, including homes, offices, data centers, and mobile networks. This environment influences the design, security, and performance of the Internet.

### Activity: Computing Systems Around Us

**Activity Tasks Detail:** Start with an introduction on computing systems. Students will then research and list various computing systems they use daily, completing a worksheet. In a group sharing session, students will discuss their findings. The class will engage in a discussion to highlight key points, and students will begin preparing a short presentation on a computing system for the next class.

**Output:** Completed worksheets, group insights, and a short presentation on a chosen computing system.

#### Internet Systems

#### Tidbits

1. When you send an email or browse the internet, data travels through cables and airwaves across the world in just seconds. It's like sending a letter that gets delivered instantly, regardless of distance!
2. The internet is one of the largest man-made systems ever created. It's a vast network of interconnected computers that communicate with each other to share information, much like how our brain's neurons communicate. When you send a message, it travels through multiple networks before reaching its destination, all within seconds.
3. Data on the internet travels at nearly the speed of light! When you send a message or browse a website, your data can cross continents almost instantaneously.
4. There are over 1.5 billion websites on the internet today, and more than 4 billion people are connected to the internet globally. That's more than half of the world's population!



## Summary

- A system is a collection of parts that work together to achieve a common goal.
- A system is described by its objective, components, communication among components and environment in which it works.
- Components are the building blocks of any system. Each component plays a specific role and contributes to the overall functionality of the system.
- The environment of a system includes everything external to the system that interacts with it. It consists of all external factors that affect system's operation.
- Systems can be broadly categorized into two types, namely natural and artificial systems.
- Natural systems are those that exist in nature and operate independently of human involvement.
- Artificial systems are designed and constructed by humans.
- Social systems are organized structures created by humans to manage social relationships, governance, and community activities.
- Computer science is the study of how computers work. It looks at what computers can do and what limitations they have.
- A computer is a complex system designed to process data and perform tasks according to a set of instructions.
- The Von Neumann architecture involves several key steps for a CPU to execute instructions, including fetching, decoding, executing, and storing.
- System software is the basic software that helps a computer run and manage its hardware and software resources.
- Application software is the software designed to help users perform specific tasks or activities.



## EXERCISE

### Multiple Choice Questions

1. What is the primary function of a system?  
a) To work independently      b) To achieve a common goal  
c) To create new systems      d) To provide entertainment
2. What is one of the fundamental concepts of any system?  
a) Its size    b) Its objective    c) Its age    d) Its price
3. What is an example of a simple system?  
a) A human body      b) A computer network  
c) A thermostat regulating temperature    d) The Internet
4. What type of environment remains unchanged unless the system provides an output?  
a) Dynamic      b) Static  
c) Deterministic      d) Non-deterministic
5. What are the basic components of a system?  
a) Users, hardware, software  
b) Objectives, components, environment, communication  
c) Inputs, outputs, processes  
d) Sensors, actuators, controllers
6. What concept does the theory of systems aim to understand?  
a) Hardware design  
b) System interactions and development over time  
c) Software applications  
d) Network security
7. What role does the Operating System (OS) play in a computer?  
a) It performs calculations and executes instructions  
b) It temporarily stores data and instructions for the CPU  
c) It receives input from interface components and decides what to do with it  
d) It provides long-term storage of data and software
8. Which of the following describes the Von Neumann architecture's main characteristic?  
a) Separate memory for data and instructions  
b) Parallel execution of instructions  
c) Single memory store for both program instructions and data  
d) Multiple CPUs for different tasks
9. What is a disadvantage of the Von Neumann architecture?  
a) Complex design due to separate memory spaces  
b) Difficult to modify programs stored in memory  
c) Bottleneck due to single memory space for instructions and data  
d) Lack of flexibility in executing instructions



10. Which of the following transports data inside a computer among different components?

- |                 |               |
|-----------------|---------------|
| a) Control Unit | b) System Bus |
| c) Memory       | d) Processor  |

**Short Questions:**

1. Define a system. What are its basic components?
2. Differentiate between natural and artificial systems.
3. Describe the main components of a computer system.
4. List and describe the types of computing systems.
5. What are the main components of the Von Neumann architecture?
6. What is the Von Neumann computer architecture? List its key components.
7. What are the four main steps in the Von Neumann architecture's instruction cycle?
8. What is the Von Neumann bottleneck?
9. What is a key advantage of the Von Neumann architecture?
10. What are the three main requirements for a computing system to function?

**Long Questions**

1. Define and describe the concept of a system. Explain the fundamental components, objectives, environment, and methods of communication within a system.
2. Differentiate between natural and artificial systems. Discuss their characteristics, functions, and purposes with relevant examples.
3. Examine the relationship between systems and different branches of science, including natural science, design science, and computer science. How do these branches utilize system theory to understand and improve their respective fields? Provide specific examples to support your analysis.
4. Explore the different types of computing systems such as computers, software systems, computer networks, and the internet.
5. Describe the main characteristics of a computer as a system, including its objectives, components, and interactions among these components.
6. Explain the Von Neumann architecture of a computer. Include a discussion on the main components, their functions, and the step-by-step process of how the architecture operates.
7. Provide a detailed explanation of how a computer interacts with its environment. Include examples of user input, network communication, and power supply.
8. Describe the process of retrieving and displaying a file using a computer, based on the interactions among different components. Provide a step-by-step explanation of how input is processed, data is transferred, and results are displayed on the screen.



# UNIT 2

## Number Systems

### Student Learning Outcomes

#### Understand Number System:

- The different numbering systems, including decimal, binary, hexadecimal, and octal, and their respective base values and digits.
- Why computers primarily use the binary number system for data representation.
- Machine-level representation of data, including how data is stored and processed within the computer's architecture.
- The representation of whole and real numbers in a computer, including binary encoding methods for both.
- How various arithmetic operations, such as addition, subtraction, multiplication, and division, are performed on binary representations of numbers?
- The concept of common text encoding schemes, such as ASCII and Unicode, and How they represent characters.
- How digital data representations work for various forms of multimedia, such as images, audios, videos, and other multimedia resources.
- Different file formats and their variations for specific applications.
- The concept of file extensions and their significance in identifying file types and applications.
- Key terms related to data representation, including ASCII, Unicode, binary, signed and unsigned numbers, bits, bytes, hexadecimal number systems, negatives in binary, two's complement, binary arithmetic, overflow, and underflow.
- The concept of Boolean functions, to represent logic operations and relationships between binary variables.
- How to construct Boolean expressions using variables and Boolean operators.
- Common Boolean identities and simplification techniques.
- The concept of duality in Boolean algebra, where OR becomes AND, and 0 becomes 1.
- The fundamentals of digital logic, which involves using binary digits (0 and 1) to process and store information.
- Difference between analog and digital signals and understanding their key differences.
- Various logic gates (AND, OR, NOT, NAND, XOR) and their functions in processing binary data.
- The purpose and construction of truth tables for evaluating the output of logic expressions based on input combinations.
- The concept of switches and their role in digital systems, often used to represent binary input.
- Karnaugh maps as a visual tool for simplifying Boolean expressions.
- Truth table, Boolean expression, circuit diagram of Half-adder and Full-adder
- Half-adder and Full-adder as digital systems with specific objectives, components and interaction among those components



## Introduction

Understanding number systems is fundamental in computer science and digital electronics. This chapter will delve into various numbering systems, their applications, and how they are used in computers. We will cover the following topics:

1. Different numbering systems: decimal, binary, hexadecimal, and octal.
2. Binary number system in computers.
3. Machine-level data representation.
4. Representation of whole and real numbers.
5. Binary arithmetic operations.
6. Common text encoding schemes: ASCII and Unicode.
7. File formats and extensions.
8. Key terms in data representation.
9. Binary data manipulation and conversion.
10. Encoding schemes.
11. Differences between file formats.
12. Storing images, audio, and video in computers.

## 2.1 Numbering Systems

Numbering systems are essential in computing because they form the basis for representing, storing, and processing data. Different numbering systems help computers perform tasks like calculations, data storage, and data transfer. These systems allow computers to represent various kinds of information, such as text, colors, and memory locations. Here is a description of a few numbering systems:

### 2.1.1 Decimal System

The decimal number system is a base-10 number system that consists of digit from 0 to 9 and we use it in everyday life. That's why each digit of the number represents a power of 10. In the decimal system the place values starting from the rightmost digits are  $10^0$ ,  $10^1$ ,  $10^2$ , and so on. For example, the decimal number 523 means:

$$5 \times 10^2 + 2 \times 10^1 + 3 \times 10^0 = 500 + 20 + 3 = 523$$

### 2.1.2 Binary System

In binary, the place values are arranged from the right to left, starting with  $2^0$ , and ending at  $2^n$ , where each position represents a power of 2. For example, the binary number 1011 can be converted to decimal as follows:

$$1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0 = 8 + 0 + 2 + 1 = 11_{10}$$

Computers work in binary system especially because this method fits well with electronics. Digital circuits have two states: They can be either on or off. These states are easily represented by the binary digits: 1 represent ON, and 0 represents OFF. When typing on the keyboard, the computer translates every



letter to a binary. Similarly, number, text, images, and sound are all, at their lowest level, reduced to binary. We shall discuss this in details later in this chapter. When you type a letter on your keyboard, the computer converts it into a binary code. Similarly, all types of data, including numbers, text, images, and sounds, are ultimately broken down into binary code. We will explore it further later in this chapter.

### 2.1.2.1 Conversion from Decimal to Binary

The following algorithm translate a decimal number to binary.

1. To convert decimal number to binary form, divide the decimal number by 2.
2. Record the remainder.
3. Divide the number by 2 until the quotient which is left after division is 0.
4. Meaning it is represented by the remainders and it's read from the bottom to the top of the binary number.

**Example: Convert 83 to binary**

$$\begin{aligned}
 83 / 2 &= 41 \text{ remainder } 1 \\
 41 / 2 &= 20 \text{ remainder } 1 \\
 20 / 2 &= 10 \text{ remainder } 0 \\
 10 / 2 &= 5 \text{ remainder } 0 \\
 5 / 2 &= 2 \text{ remainder } 1 \\
 2 / 2 &= 1 \text{ remainder } 0 \\
 1 / 2 &= 0 \text{ remainder } 1
 \end{aligned}$$

The above steps are graphically shown in Figure 2.1. If the remainders are read from bottom to top then it gives the required result in binary, which is 1010011.

2	83
2	41—1
2	20—0
2	10—0
2	5—1
2	2—1
2	1—0
	0—1



Figure 2.1 Decimal to Binary conversion



### Class activity

1. **Marks Conversion:** Each student will take his or her marks from 8<sup>th</sup> grade for each subject and convert them from decimal to binary. For example, if a student score 85 in Math, he/she will convert 85 to binary (which is 1010101).
2. **Clock Time Conversion:** Students will be given various times of the day and asked to convert them into binary. For instance, 3:45 PM would be converted as follows:  
Hours (15) = 1111  
Minutes (45) = 101101
3. Write your sleeping time in binary.

### 2.1.3 Octal System

Octal is a positional numeral system with base eight, which implies that a digit to be used ranges from 0 to 7. The last digit is a single digit power of 8 while the other digits are the coefficients. In the decimal system, the place values starting from the  $8^0$ ,  $8^1$ ,  $8^2$  and so on. For example, the octal number 157 means,  $1 \times 8^2 + 5 \times 8^1 + 7 \times 8^0 = 64 + 40 + 7 = 111_{10}$ .

Each octal digit represents three binary digits (bits) because the octal system is base-8, and the binary system is base-2. This relationship arises from the fact that 8 is a power of 2 ( $8 = 2^3$ ). So, each octal digit can be precisely represented by three binary digits (bits). This means that any value from 0 to 7 in octal can be converted into a 3-bit binary number. This relationship makes conversion between binary and octal straight forward. Table 2.1 shows the correspondence between octal and binary digits:

#### Example:

Consider the 9-bit binary number 110101011. This number can be divided into groups of three

Bits from right to left:

110 101 011

Each group of three bits corresponds to a single octal digit:

$$110 = 6$$

$$101 = 5$$

$$011 = 3$$



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

**Table 2.1: Correspondence between Octal and Binary Digits**

So, the binary number 110101011 is equal to 653 in octal.

Note that the octal number system isn't actually used in modern computers to do their work. Therefore, we can say that the binary number 110101011 is equal to 653 in octal. Whenever you have a binary number that cannot be divided into groups of a three, you'll have to add zero up to the left end of it to make it appropriate.

### 2.1.3.1 Conversion from Decimal to Octal

The algorithm below translates a decimal number into an octal.

1. To convert the decimal number to an equivalent octal number, divide the number by 8.
2. Write down the remainder.
3. After that divide the obtained quotient by 8.
4. Continue the divisions until one of the numbers results in 0.
5. Octal is a base eight number and the octal number is the remainder read from the bottom up to the top.

8		83	
8		10	— 3
8		1	— 2
		0	— 1



**Figure 2.2: Conversion from Decimal to Octal.**

#### **Example: Convert 83 to octal**

- $83 / 8 = 10$  remainder 3
- $10 / 8 = 1$  remainder 2
- $1 / 8 = 0$  remainder 1

The above steps are graphically shown in Figure 2.2. Going up from bottom, the remainder reading will give the desired result, that is 123 in the octal system.

#### **Class activity**

1. Work in pairs to convert the following decimal numbers to octal: 45, 128, 64.
2. Convert these octal numbers to decimal: 57, 124, 301.
3. Share your answers with the class and discuss any differences.





The octal system was used in early computing systems like PDP-8. It was used because it is easier to convert between octal and binary than between decimal and binary.

### Tidbits

When converting between number systems, double-check your remainders and sums to ensure accuracy. Practice with different numbers to become more comfortable with the conversion process.

## 2.1.4 Hexadecimal System

The hexadecimal is a base 16 number system with digit number from 0 to 9 and alphabets from A to F; each digit represents 16 to the power of the position of the digit. The letter A to F stand for the numeric value of 10 to 15. The digits in hexadecimal move from right to left in place value that are  $16^0$ ,  $16^1$ ,  $16^2$ ... and so on. For example, the hexadecimal number 1A3 can be represented in decimal as:

$$1 \times 16^2 + A \times 16^1 + 3 \times 16^0 = 1 \times 256 + 10 \times 16 + 3 \times 1 = 256 + 160 + 3 = 419_{10}$$

The hexadecimal number system is not directly used by computers either. However, it provides an even more compact representation than octal. This makes it easier for us to read and write large binary numbers.

This is because the hexadecimal system is base-16 and the binary system is base-2, therefore every single hexadecimal digit equals four binary bits. This relationship stems from the fact that 16 is a power of 2 ( $16 = 2^4$ ). This means that any hexadecimal number between 0 and 15 then it can be converted into 4-bit binary number.

Table 2.2 illustrates conversion of hexadecimal to binary digits. Each group of four bits corresponds to a single hexadecimal digit.

### Example:

Therefore, the binary number 1101011010110010 equals to the hexadecimal number D6B2. In case a binary number cannot be grouped as four bits add zero(s) to the left of the number to make it fit.

1101 0110 1011 0010



Hexadecimal	Binary
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 2.2: Correspondence between Hexadecimal and Binary Digits**

1101 = D

0110 = 6

1011 = B

0010 = 2

#### 2.1.4.1 Converting Decimal to Hexadecimal

The following algorithm converts a decimal number to hexadecimal:

1. Convert the decimal number to an absolute value by dividing it by 16.
2. Record the quotient and the remainder.
3. Continue dividing the quotient by 16 and write down the remainder until the quotient is zero.
4. The hexadecimal number, as you might have guessed, is the remainder read from bottom to top.

**Example: Convert 2297 to hexadecimal**



$$2297 / 16 = 143 \text{ remainder } 9$$

$$143 / 16 = 8 \text{ remainder } F$$

$$8 / 16 = 0 \text{ remainder } 8$$

16		2297	
16		143 — 9	⇒ 9
16		8 — 15	⇒ F
		0 — 8	⇒ 8 ↑

Figure 2.3: Decimal to Hexadecimal

The above steps are graphically shown in Figure 2.3. Reading the remainders from bottom to top gives the required result, i.e., 8F9 in hexadecimal.

### Class activity

Find the following values and express them in hexadecimal. Discuss your findings with your classmates:

- Minimum Age to Cast Vote
- Length of the Indus River
- Total Districts in Pakistan
- Height of K2 (the second-highest mountain in the world)
- Area of Pakistan

## 2.2 Data Representation in Computing Systems

Computers can process and store a lot of information. In the following section we will discuss numeric data representation.

### 2.2.1 Binary Encoding of Integers (Z) and Real Numbers (R)

When we store data in computers, especially numbers, it's important to understand how they are represented and stored in memory. Let's explore how different sizes of integer values are stored in 1, 2, and 4 bytes, and how both positive and negative integers are handled.

### 2.2.2 Whole Numbers (W) and Integers (Z)

Integers, also known as whole numbers, are important elements in both mathematics and computer science. Knowledge of these concepts is important for primary computations, solving problems through programming, working with data and designing algorithms.

#### 2.2.2.1 Whole Numbers (W)

Whole numbers are a set of non-negative integers. They include zero and all the positive integers. Mathematically, the set of whole numbers is:

$$W = \{0, 1, 2, 3, \dots\}$$

In computing, whole numbers are often used to represent quantities that can't be negative. Examples include the number of students in a school, a person's age



in years, and grades, provided there are no negative figures such as credit point balances.

A 1-byte integer has 8 bits to store values. If all 8 bits are on, it represents the maximum value,  $11111111_2$ , which is  $255_{10}$ . If all bits are off, it represents the minimum value,  $00000000_2$ , which is  $0_{10}$ . Similarly, using 2 or 4 bytes, we get more bits to store data allowing us to store bigger values. If  $n$  is the number of bits, the maximum value that can be represented is  $2^n - 1$  for examples:

- 1-Byte whole number (8 bits): Maximum value =  $2^8 - 1 = 255$
- 2-Byte whole number (16 bits): Maximum value =  $2^{16} - 1 = 65,535$
- 4-Byte whole number (32 bits): Maximum value =  $2^{32} - 1 = 4,294,967,295$

### 2.2.2.2 Integers (Z)

Integers extend the concept of whole numbers to include negative numbers. In computer programming, we call them signed integers. The set of integers is represented as:

$$Z = \{\dots, -3, -2, -1, 0, 1, 2, 3, \dots\}$$

To store both positive and negative values, one bit is reserved as the sign bit (the most significant bit). If the sign bit is ON(1), the value is negative; otherwise, it is positive. Using this system, the maximum positive value that can be stored in a 1 byte signed integer is  $(01111111)_2$ , which is  $127_{10}$ . As the bits available to stored a value is  $n - 1$ , hence the maximum value will be  $2^{n-1} - 1$ . We can use this formula to compute the maximum values for 2 and 4 bytes.

Negative values are stored using two's complement, explained in the following section.

### 2.2.2.3 Negative Values and Two's Complement

To store negative values, computers use a method called two's complement. To find the two's complement of a binary number, follow these steps:

1. Invert all the bits (change 0s to 1s and 1s to 0s).
2. Add 1 to the Least Significant Bit (LSB).

**Example:** Let's convert the decimal number -5 to an 8-bit binary number:

1. Start with the binary representation of 5:  $0000101_2$ .
2. Invert all the bits:  $11111010_2$ .
3. Add 1:  $11111010_2 + 1_2 = 11111011_2$ .

So, -5 in 8-bit two's complement is  $11111011_2$ .

#### Minimum Integer Value

For an 8-bit integer, we switch on the sign bit for the negative value and turn all bits ON. resulting in  $11111111_2$ . Except the first bit, we take two's complement and get  $10000000_2$  which is  $128_{10}$ . Thus minimum value in 1-byte signed integer is -128, i.e.,  $-2^7$ . The minimum value is computed using the formula  $-2^{n-1}$ , where  $n$  is the total number of bits.

- **2-Byte Integer (16 bits):** Minimum value =  $-2^{15} = -32,768$



- **4-Byte Integer (32 bits):** Minimum value =  $-2^{31}-1 = -2,147,483,648$



The reason we use binary and these ranges is that computers use transistors that have two states: ON (1) and OFF (0). This binary system forms the foundation of all digital computing!

**Top Tip:** When working with different integer types, always check whether the data type is signed or unsigned to avoid unexpected results, especially when dealing with large values or negative numbers.

Understanding how integers are stored in memory helps you appreciate the inner workings of computers and ensures you can effectively work with different data types in programming.

## 2.3 Storing Real Values in Computer Memory

In computers, real values, also known as floating-point numbers, are used to represent number with fractions and/or decimals.

### 2.3.1 Understanding Floating-Point Representation

Floating-point numbers (real values) are represented similarly to scientific notation as given below:

A floating-point number = sign x mantissa x  $2^{\text{exponent}}$ . According to the above formula, 5.75 is represented as  $1.4375 \times 2$ . To convert the fractional part of a real (floating-point) number from decimal (base-10) to binary (base-2), multiply the fractional part by 2 and write down the integral part of the result. Repeat this process with the new fractional part until the value of the fractional part becomes zero or until the required precision is achieved.

#### Steps for Conversion:

1. **Identify the Fractional Part:** Get the fractional part of the decimal number. For instance, in the number 4.625, the integral part is 4 and the fractional part is 0.625.
2. **Convert the Fractional Part to Binary:** Multiply the fractional part by 2, and write down the integer that is obtained. Repeat this process with the new fractional part till it gets to 0 or until then required number of decimal places is achieved.

**Example:** Converting 0.375 to Binary

1. **Identify the Fractional Part:** Fractional part: 0.375
2. **Convert the Fractional Part 0.375 to Binary:**



$$0.375 \times 2 = 0.75 \text{ (Integer part: 0)}$$

$$0.75 \times 2 = 1.5 \text{ (Integer part: 1)}$$

$$0.5 \times 2 = 1.0 \text{ (Integer part: 1)}$$

The integer parts recorded are 0, 1, 1.

3. Combine the Results: Combine the binary representations of the integer parts from top to bottom:

$$0.375_{10} = 0.011_2$$

In computing, it is critical to express real numbers in a binary form since it facilitates computing and storage. This process involves converting both the integer (decimal) and the fractional parts of a given number into binary. Two commonly use standards for this representation are "Single precision (32-bit)" and "Double Precision (64-bit)".

### 2.3.1.1 Single Precision (32-bit)

In this standard, 4 bytes (or 32 bits) are assigned where the 1st bit is the sign bit, and the next 8 bits are for the exponent and the remaining 23 bits are for the mantissa.

Here the exponent can be ranged between  $-126$  and  $+127$ .

The approximate range of values from  $1.4 \times 10^{-45}$  to  $3.4 \times 10^{38}$ .

Value	Representation	Sign Bit	Exponent (8 bits)	Mantissa (23 bits)
Grouping		1 bit	8 bits	23 bits
5.75	$1.4375 \times 2^2$	0	10000001	10111000000000000000000
-5.75	$-1.4375 \times 2^2$	1	10000001	10111000000000000000000
0.15625	$1.25 \times 2^{-3}$	0	01111101	01000000000000000000000
-0.15625	$-1.25 \times 2^{-3}$	1	01111101	01000000000000000000000

**Table 2.3: 32-bit Floating Point Representation**

#### Explanation:

Table 2.3 illustrates how 32-bit floating point values are represented in binary form. Each floating point value is broken down into three main components: the sign bit, the exponent, and the mantissa.

1. **Grouping:** This row explains the bit allocation for the 32-bit floating point format: 1 bit for the sign, 8 bits for the exponent, and 23 bits for the mantissa.



1. **5.75:** Representation:  $1.4375 \times 2^2$  - Sign Bit: 0 (positive) - Exponent:  $2 + 127 = 129$ , which is  $10000001_2$  - Mantissa: The binary representation of 0.4375 is  $10111000000000000000000_2$
2. **-5.75:** Representation:  $-1.4375 \times 2^2$  - Sign Bit: 1 (negative) - Exponent:  $2 + 127 = 129$ , which is  $10000001_2$  - Mantissa: The binary representation of 0.4375 is  $10111000000000000000000_2$
3. **0.15625:** Representation:  $1.25 \times 2^{-3}$  - Sign Bit: 0 (positive) - Exponent:  $-3 + 127 = 124$ , which is  $01111101_2$  - Mantissa: The binary representation of 0.25 is  $01000000000000000000000_2$
4. **-0.15625:** Representation:  $-1.25 \times 2^{-3}$  - Sign Bit: 1 (negative) - Exponent:  $-3 + 127 = 124$ , which is  $01111101_2$  - Mantissa: The binary representation of 0.25 is  $01000000000000000000000_2$

This breakdown helps illustrate how floating point values are stored and manipulated in computer systems

### 2.3.1.2 Double Precision (64-bit)

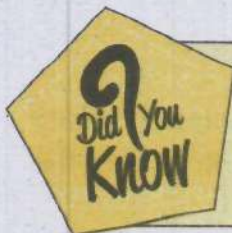
In double precision, the exponent is represented using 11 bits. The exponent is stored in a biased form, with a bias of 1023. The range of the actual exponent values can be determined as follows:

- **Bias:** 1023
- **Exponent range:** The actual exponent values range from -1022 to +1023.

Therefore, the smallest and largest possible exponent values in double-precision are:

- **Minimum exponent:** -1022
- **Maximum exponent:** +1023

We can perform the same steps given for the single-precision, except the difference of the abovementioned values.



The smallest positive number representable in single precision is approximately  $1.4 \times 10^{45}$  and in double precision is approximately  $4.9 \times 10^{-324}$ !

### Tidbits

When performing computation with floating point values one should also consider possible round off errors. In scientific computing, it is necessary to monitor these errors to maintain the accuracy.



### Class activity

1. Write down the binary representation of the following decimal numbers: 2, 5, 7, 25, and 10.5.
2. Then, convert these binary representations to the format single precision format.
3. After completing this operation, discuss with classmates and yourself how the degree of accuracy of the representation differs based on the size of the number?

The information about how real values is stored in computer memory help us understand the precision and limitations of digital computation. With this understanding of floating-point representation, it becomes possible to control and manipulate these numbers in different ways.

## 2.4 Binary Arithmetic Operations

Arithmetic operations include addition, subtraction, multiplication and division, and are performed on two numbers at a time. Binary arithmetic operations are similar to decimal operations but follow binary rules. Here's a brief overview of the basic operations:

### 2.4.1 Addition

Binary addition uses only two digits: 0 and 1. Here, we will learn how to add binary numbers and how to handle the addition of negative binary numbers.

#### Binary Addition Rules

Binary addition follows these simple rules:

1.  $0 + 0 = 0$
2.  $0 + 1 = 1$
3.  $1 + 0 = 1$
4.  $1 + 1 = 0$  (with a carry of 1 to the next higher bit)

#### Example of Binary Addition

Example 1:

$$\begin{array}{r} 1101 \\ +1011 \\ \hline 11000 \end{array}$$

In this example:

- $1 + 1 = 0$  (carry 1)
- $0 + 1 + 1$  (carry) = 0 (carry 1)
- $1 + 0 + 1$  (carry) = 0 (carry 1)
- $1 + 1 + 1$  (carry) = 1 (carry 1)



## 2.4.2 Subtraction

In binary arithmetic, subtraction can also be carried out by adding the two's complement or the value of the subtrahend to the minuend.

### Example: Subtract 6 from 9 in Binary

$$\text{Minuend} = 9_{10} = 1001_2$$

$$\text{Subtrahend} = 6_{10} = 0110_2$$

#### Step 1: Find the Two's Complement of the Subtrahend

- Invert the bits of  $0110_2$ :  
Inversion:  $1001_2$
- Add 1 to the inverted number:  
 $1001_2 + 1_2 = 1010_2 = -6_{10}$

#### Step 2: Add the Minuend and the Two's Complement of the Subtrahend

$$1001_2 + 1010_2 = 10011_2$$

#### Step 3: Discard the Carry Bit

$$10011_2 \quad \text{Discard carry} \quad 0011_2 = 3_{10}$$

$$\text{So, } 9 - 6 = 3.$$

## 2.4.3 Multiplication

Binary numbers are base-2 numbers, consisting of only 0s and 1s. Multiplying binary numbers follows similar principles to multiplying decimal numbers, but with simpler rules. Here, we will learn how to multiply binary numbers with example.

### Steps to Multiply Binary Numbers

1. Write down the binary numbers, aligning them by the least significant bit (rightmost bit).
2. Multiply each bit of the second number by each bit of the first number, similar to the long multiplication method in decimal.
3. Shift the partial results one place to the left for each new row, starting from the second row.
4. Add all the partial results to get the final product.

### Example

Let's multiply two binary numbers:  $101_2$  and  $11_2$ .

$$\begin{array}{r} 101 \\ \times 11 \\ \hline 101 \\ 101 \times \\ \hline 1111 \end{array} \quad \begin{array}{l} \text{(This is } 101_2 \times 1_2) \\ 0 \text{ (This is } 101_2 \times 1_2 \text{, shifted left)} \end{array}$$

So,  $101_2 \times 11_2 = 1111_2$ .





The Central Processing Unit (CPU) of a computer performs millions of binary multiplications every second to execute complex instructions and run programs!

### 2.4.3 Division

Binary division is similar to decimal division but only involves two digits: 0 and 1. It follows steps like comparing, subtracting, and shifting, akin to long division in the decimal system.

#### Steps of Binary Division

1. **Compare:** Compare the divisor with the current portion of the dividend.
2. **Subtract:** Subtract the divisor from the dividend portion if the divisor is less than or equal to the dividend.
3. **Shift:** Shift the next binary digit from the dividend down to the remainder.
4. **Repeat:** Repeat the process until all digits of the dividend have been used.

#### Example

Divide  $1100_2$  by  $10_2$

$$\begin{array}{r} 10 \overline{) 1100} \quad 110 \\ \underline{-10} \phantom{0} \\ 10 \\ \underline{-10} \\ 0 \end{array}$$

(Step 1: Compare 10 with first two 11, subtract 10 from 11)

(Step 2: Bring down the next digit 0)

(Step 3: Compare 10 with 10, subtract 10 from 10)

(Step 4: Bring down the next digit 0, no more digits left)

Result:  $1100_2 / 10_2 = 110_2$

#### Class activity

##### Practicing Binary Division

Objective: To practice and understand binary division through hands-on examples.

##### Instructions:

1. Form groups of three to four students.
2. Each group will solve the following binary division problems:
  - (a)  $10101_2 \div 10_2$
  - (b)  $11100_2 \div 11_2$
  - (c)  $100110_2 \div 101_2$
3. Write down each step of your division process clearly.
4. Present your solutions to the class, explaining each step and the reasoning behind it.



## 2.5 Common Text Encoding Schemes

Text encoding schemes are essential for representing characters from various languages and symbols in a format that computers can understand and process. Here are some of the most common text encoding schemes used in computers:

### 2.5.1 ASCII

ASCII is an acronym that stands for American Standard Code for Information Interchange. It is a character encoding standard adopted for representing in devices such as computers and similar systems that use text. Each alphabet, number or symbol is given a code number between 0 and 127 as shown in Table 2.4.

ASCII enables different computers and devices to exchange text information reliably. Let's encode the name of our country using ASCII.

- The ASCII code for an upper case letter "P" is 80.
- The code for letter 'a' in ASCII is 97.
- The ASCII code for the letter 'k' is 107.
- It is interesting to know that the ASCII code for the letter 'i' is 105.
- In the ASCII code system, the letter 's' has a code of 115.
- The code for 't' is 116 in ASCII.

The ASCII code is a numerical representation of characters in computer-based system, particularly for alphabetic characters.

For example, the ASCII code of the character 'n' is 110.

#### Class activity

1. Write down your name.
2. Find the ASCII code for each letter in your name. You can use the ASCII table to for your help.
3. Convert each ASCII code to binary.
4. Write down your name in binary!



Character	ASCII Code	Character	ASCII Code
SP (space)	32	!	33
"	34	#	35
\$	36	%	37
&	38	'	39
(	40	)	41
*	42	+	43
,	44	-	45
.	46	/	47
0	48	1	49
2	50	3	51
4	52	5	53
6	54	7	55
8	56	9	57
:	58	;	59
<	60	=	61
>	62	?	63
@	64	A	65
B	66	C	67
D	68	E	69
F	70	G	71
H	72	I	73
J	74	K	75
L	76	M	77
N	78	O	79



P	80	Q	81
R	82	S	83
T	84	U	85
V	86	W	87
X	88	Y	89
Z	90	[	91
\	92	]	93
^	94	-	95
?	96	a	97
b	98	c	99
d	100	e	101
f	102	g	103
h	104	i	105
j	106	k	107
l	108	m	109
n	110	o	111
p	112	q	113
r	114	s	115
t	116	u	117
v	118	w	119
x	120	y	121
z	122	{	123
	124	}	125
~	126	DEL	127

Table:2.4



### 2.5.1 Extended ASCII

While the standard ASCII Table includes 128 characters, there is an extended version that includes 256 characters. This extended ASCII uses 8 bits and includes additional symbols, accented letters, and other characters. However, the original 128 characters are the most commonly used and serves as the basis for text representation in computers.

### 2.5.2 Unicode

Unicode is an attempt at mapping all graphic characters used in any of the world's writing system. Unlike ASCII, which is limited to 7bits and can represent only 128 characters, Unicode can represent over a million characters through different forms of encodings such as, UTF-8, UTF-16, and UTF-32. UTF is an acronym that stands for Unicode Transformation Format.

#### 2.5.2.1 UTF-8

It is a variable-length encoding scheme, meaning it can use a different numbers of bytes (from 1 to 4) to represent a character. UTF-8 is backward compatible with ASCII. It means it can understand and use the older ASCII encoding scheme without any problems. Therefore, if we have a text file written in ASCII, it will work perfectly fine with UTF-8, allowing it to read both old and new texts.

**Example:** The letter 'A' is Unicode, represented as, U+0041, is 01000001 in the binary format and occupies 8 bits or 1 byte.

Let's look at how Urdu letters are represented in UTF-8:

**Example:** The Urdu letter 'پ' is represented in Unicode as U+0628; its binary format is 11011000 10101000, means it takes 2 bytes.

#### 2.5.2.2 UTF-16

UTF-16 is another variable character encoding mechanism, although it uses either 2 bytes or 4 bytes per character at most. Unlike UTF-8, it is not compatible with ASCII, meaning it cannot translate ASCII code.

**Example:** The letter A in UTF-16 is equal to 00000000 01000001 in binary or 65 in decimal (2 bytes).

**For Urdu:**

**Example:** The right Urdu letter 'پ' in UTF-16 is represented as is 00000110 00101000 in binary, which occupies 2 bytes of memory.

#### 2.5.2.3 UTF-32

UTF-32 is a method of encoding that uses a fixed length, with all characters stored in 4 bytes per character. This makes it very simple but at the same time it may look a little complicated when it comes to space usage.

**Example:** Alphabet letter 'A' in UTF-32 is represented in binary as 00000000 00000000 00000000 01000001 which is 4 bytes.



## 2.6 Storing Images, Audio, and Video in Computers

Have you ever wondered how your favorite photos, songs, and movies are stored on your computer or phone? Let's dive into the fascinating world of digital storage to understand how computers manage these different types of files.



Data size is usually expressed in byte and its multiples.

- 1 Byte (B) = 8 Bits
- 1 Kilobyte (KB) = 1024 Bytes
- 1 Megabyte (MB) = 1024 Kilobytes
- 1 Gigabyte (GB) = 1024 Megabytes
- 1 Terabyte (TB) = 1024 Gigabytes
- 1 Petabyte (PB) = 1024 Terabytes
- 1 Exabyte (EB) = 1024 Petabytes
- 1 Zettabyte (ZB) = 1024 Exabytes
- 1 Yottabyte (YB) = 1024 Zettabytes

### 2.6.1 Storing Images

Images are made up of tiny dots called **pixels**. Each pixel has a color, and the combination of all these pixels forms the complete picture. Computers store images using numbers to represent these colors.

**Color Representation:** - In a color image, each pixel's color can be represented by three numbers: Red, Green, and Blue (RGB). Each of these numbers typically ranges from 0 to 255. - For example, a pixel with RGB values (255, 0, 0) will be bright red.

**Image File Formats:** The following are Commonly used image formats for photos - **JPEG** (Joint Photographic Expert Group). It compresses the image to save space but might lose some quality. - **PNG** (Portable Network Graphics): Supports transparency and maintains high quality without losing data. - **GIF** (Graphics Interchange Format): Used for simple animations and images with few colors.

#### Class activity

##### Create a Pixel Art

1. Use graph paper to draw a simple image, such as a smiley face.
2. Color each square (pixel) and write down the RGB values for each color used.
3. Share your pixel art and RGB values with the class.



## 2.6.4 How Computers Store These Files

All these files (images, audio, and video) are stored as **binary data**, which means they are represented by sequences of 0s and 1s.

### Storage Devices:

- **Hard Disk Drive (HDD):** Uses spinning disks to read/write data. They offer large storage capacities.
- **Solid State Drive (SSD):** Uses flash memory for faster access times and better performance.
- **Cloud Storage:** Stores files on remote servers accessible via the internet, providing flexibility and backup options.



IBM created the first hard drive in 1956 which weighed over a ton and could only store 5,000,000 bytes which is much less than the storage required for even one high-quality song today.

This leads us to an understanding and appreciation of how images, audio and videos are stored in the computers, allowing us to marvel at the underlying technology of our current digital age. Whether you're taking pictures, enjoying music, or watching films, it all stems how computers manage information!

### Summary

- In computing, numbering systems are crucial as they form the foundation for representing, storing, and processing information.
- Decimal number system is a number system in which base is 10 and the digits involved are 0 to 9, which are commonly used in our daily lives.
- Binary is a base-2 number system that comprises of only the digits 0 and 1. Each digit represents a power of two.
- The Octal number system is another number system that has eight as its base; thus, it has eight digits 0 to 7. Each digit represents a power of 8, this can be expressed as 8 digit.
- The Hexadecimal numbering system is another type of number system with base of 16, where the number 0 to 9 and alphabets A-F are used.
- Integers refers to the set of non-negative whole numbers, while whole numbers are the complete numbers. They include zero and all the positive integers, also positive zero.
- To store negative values, computers employ a technique commonly known as two's complement.
- In computers, real values, which are nicknamed as floating-point numbers are used to represent numbers with fraction or decimal point.
- Arithmetic operations mean addition, subtraction multiplication, and division performed on numbers in given base. Binary arithmetic involves performing these operations on numbers in binary form, or base 2.
- ASCII is an acronym for American Standard Code for Information Interchange. It is an industry standard used to encode text in computers and



6. What is the primary difference between signed and unsigned integers?
- Unsigned integers cannot be negative
  - Signed integers have a larger range
  - Unsigned integers are stored in floating-point format
  - Signed integers are only used for positive numbers
7. In the single precision, how many bits are used for the exponent?
- 23 bits
  - 8 bits
  - 11 bits
  - 52 bits
8. What is the approximate range of values for single-precision floating-point numbers?
- $1.4 \times 10^{-45}$  to  $3.4 \times 10^{38}$
  - $1.4 \times 10^{-38}$  to  $3.4 \times 10^{45}$
  - $4.9 \times 10^{-324}$  to  $1.8 \times 10^{308}$
  - $4.9 \times 10^{-308}$  to  $1.8 \times 10^{324}$
9. What are the tiny dots that make up an image called?
- Pixels
  - Bits
  - Bytes
  - Nodes
10. In an RGB color model, what does RGB stand for?
- Red, Green, Blue
  - Red, Gray, Black
  - Right, Green, Blue
  - Red, Green, Brown

### Short Questions

- What is the primary purpose of the ASCII encoding scheme?
- Explain the difference between ASCII and Unicode.
- How does Unicode handle characters from different languages?
- What is the range of values for an unsigned 2-byte integer?
- Explain how a negative integer is represented in binary.
- What is the benefit of using unsigned integers?
- How does the number of bits affect the range of integer values?
- Why are whole numbers commonly used in computing for quantities that cannot be negative?
- How is the range of floating-point numbers calculated for single precision?
- Why is it important to understand the limitations of floating-point representation in scientific computing?

### Long Questions

- Explain how characters are encoded using Unicode. Provide examples of characters from different languages and their corresponding Unicode code points.
- Describe in detail how integers are stored in computer memory.
- Explain the process of converting a decimal integer to its binary representation and vice versa. Include examples of both positive and



negative integers.

4. Perform the following binary arithmetic operations:

a. Multiplication of 101 by 11.

b. Division of 1100 by 10.

6. Add the following binary numbers:

a)

$$\begin{array}{r} 101 \\ + 110 \\ \hline \end{array}$$

b)

$$\begin{array}{r} 1100 \\ + 1011 \\ \hline \end{array}$$

7. Convert the following numbers to 4-bit binary and add them:

(a)  $7 + (-4)$

(b)  $-5 + 3$

8. Solve the following

(a)  $1101_2 - 0100_2$

(b)  $1010_2 - 0011_2$

(c)  $1000_2 - 0110_2$

(d)  $1110_2 - 100_2$



# UNIT 3

## Digital Systems and Logic Design

### Student Learning Outcomes

By the end of this chapter, you will be able to:

- Understand Boolean functions and operations it, such as Boolean AND, and OR.
- Construct Boolean expressions using variables and Boolean operators.
- Relate common Boolean identities and Boolean simplification procedures.
- Understand the concept of duality in Boolean algebra.
- Subtopics such analog and digital signals
- Introduce several types of gates and their functions.
- Build truth tables for the operations of logical expressions.
- Employ the K-Maps in minimizing Boolean expressions.
- Introduce logic diagrams of digital system.
- Analyze and design half-adder and full-adder circuits.



## Introduction

In this chapter, we will discuss the Boolean functions, logic, digital logic, and difference between analog and digital signals. We will also discuss several types of gates, their truth tables, and digital devices including half and full adders. At the completion of this chapter, you should be able to construct Boolean expressions, simplify them, create truth table, and understand the basics of digital logic.

## 3.1 Basics of Digital Systems

Digital systems are the backbone of today's electronics and computing. They manipulate digital information in the form of binary digits, which are either 0 or 1 and are used in calculation devices such as calculators and computers, among others.

### 3.1.1 What is an Analog Signal

Analog signals are signals that change with time smoothly and continuously over time. They can have any value within a given range. Examples include voice signal (speaking), body's temperature and radio-wave signals. Digital signals are the signals which have only two values that are in the form of '0' and '1'. These are utilized in digital electronics and computing systems. Analog to digital converter (ADC) and digital to analog converters (DAC) are important operations in today's technological developments, enabling the transmission and control of signals.

Analog Signal	Digital Signal
Continuous Infinite possible values Example: Sound waves	Discrete Finite (0 or 1) Example: Binary data in computers

**Analog to Digital Conversion (ADC):** ADC is the conversion of analog signals into digital signals, which are discrete and can be easily processed by computerized devices like computers and smart phones.

**Digital to Analog Conversion (DAC):** DAC is the conversion whereby analog signals are converted to digital signals, making it possible for human to perceive the information, for instance through speakers, as depicted in figure 3. 1.



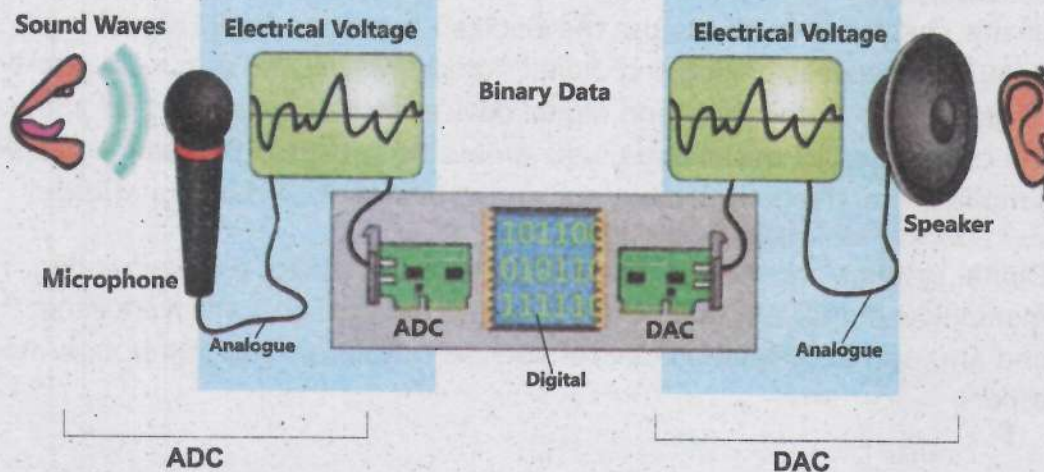


Figure 3.1: Analog to Digital and Vice Versa

### ADC and DAC Conversion: Why is it needed?

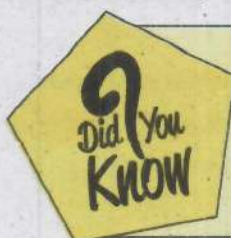
Digital to analog conversion, and vice versa, is critical since it enables data processing, storage, and transmission. Digital signals are much less affected by noise and signal degradation and are therefore better suited for transmitting and storing information over long distances.

#### Example: Sound Waves

Let us consider a situation where one person is speaking into a microphone while the other person is receiving sound through speakers as illustrated in the figure 3.1.

**1. Microphone (ADC):** When you speak into the microphone, your voice produces sound waves (analog signals) that are captured by the system. This is done by converting the sound waves into digital form using an ADC with the microphone. Finally, this digital data can be transmitted over long distances with little or no degradation in quality.

**2. Speakers (DAC):** At the receiver end, the digital signals are then converted back into analog signals with the help of DAC. The speakers then translate these analog signals back into sound waves to enable you hear to the other person's voice as if they were speaking directly to you.



Analog signals are sometimes changed to digital signals in an action known as Analog to Digital Conversion or ADC. This enables analog information such as music, to be recorded and manipulated by digital gadgets.



### 3.1.2 Fundamentals of Digital Logic

Digital logic is the basis of digital systems. It involves the use of binary numbers that is 0 and 1, to represent and manipulate information. Digital logic circuits use of these binary values to perform various operations, and they are essential to the functioning in operation of computers and many other electronic devices.

In digital circuits, the two states, 0 and 1, are represented by different voltage levels. Conventionally, a higher voltage, such as, 5 volts refer to a binary '1', while a low voltage, for instance, 0 volts refer to a binary '0'. These voltage levels are termed as the logic levels. Logic levels are needed to switch on and switch off the devices and to define ways through which digital circuits execute operations and process information.

## 3.2 Boolean Algebra and Logic Gates

Boolean algebra is a branch of mathematics relate to logic and symbolic computation, using two values namely True and False. It is an essential branch of digital circuits since it is the basis for the analysis and design of circuits. Here in this section we will cover of Boolean functions and expressions, the working, and functions of logic gates, Building and evaluating Truth Tables and Logic Diagrams.

### 3.2.1 Boolean Functions and Expressions

Binary values are used to describe the relationship between variables in the Boolean function and Boolean expressions. The expressions are built using AND, OR, and other logic operations and can in several ways be reduced to optimize digital circuits.

#### 3.2.1.1 Binary Variables and Logic Operations

Binary variables that can have only have two values, 0 and 1. Logic operations are basic operations implemented in Boolean algebra for processing of these binary variables. The primary logic operations are AND, OR and NOT.

##### **AND Operation:**

AND is the basic logical operator which is used in Boolean algebra. It requires two binary inputs which will give a single binary output. The symbol '.' is used for the AND operation. The output of the AND operation is "1" only when both inputs are "1". Otherwise, the result is "0".

##### **Example:**

Consider two binary variables:

$$A = 1(\text{True})$$

$$B = 0(\text{False})$$

The AND operation for these variables can be written mathematically as:

$$P = A \cdot B$$

In this example:

$$A=1 \quad B = 0$$

Therefore, then, the result P of the AND operation is 0 (false).



**Truth Table:**

A truth table is useful in demonstrating the functionality of the AND operation with all possibilities of the input variables. Below is the truth table for the AND operation.

A	B	A AND B (P)
0	0	0
0	1	0
1	0	0
1	1	1

Table 3.1: Truth Table for AND Operation

**Explanation:**

If both A and B are off, that is equal to zero then the desired output P is off (0).

if A is 0 and B is 1 the output P is 0.

When A is 1 and B is 0 P is resulting 0.

When A is 1 and B is 1, the output P also becomes 1.

**OR Operation:**

The OR operation is an other basic logical operator in Boolean algebra. To be specific this is also a function tables two binary variables as input produces a single binary output. According to Table 3.2, the OR operation yields true (1) output when at least of '1' of the inputs is true (1). The output is 0 only when both inputs are '0'.

**Example:**

Consider two binary variables:

A = 1 (true)

B = 0 (false)

The OR operation for these variables can be written mathematically as:

$$P = A + B$$

In this example:

$$A = 1 \quad B = 0$$

Therefore, result P of the OR gate will be 1.

**Truth Table:**

A truth table is useful for better understanding of how the OR operation is organized and what the result of the OR's application is for all variants of the input variables. Below is the truth table for the OR operation.



**Explanation:**

If A is equal to 0 and B is equal to 0 the output P is equal to 0. When A is zero and B is one, the output P is also one. When A is equal to 1 and B is equals to 0 the values of P equal to 1. When both A and B are 1 then the output P equal to one.

A	B	A OR B (P)
0	0	0
0	1	1
1	0	1
1	1	1

Table 3.2: Truth Table for OR Operation



In binary logic,  $1 + 1$  does not equal 2 but equals 1 in logical operation. This is because the OR operation returns a value of 1 if any or both of the inputs to this operator are 1.

**NOT Operation:**

The NOT operation is one of the basic Boolean algebra operations which takes a single binary variable and simply negates its value. If the input is one, the output is zero and if the input is zero, the output is one.

Example:

Consider a binary variable:

$$A = 1 \text{ (true)}$$

The NOT operation for this variable can be written mathematically as:

$$P = \bar{A} \quad \text{or} \quad P = \neg A$$

In this example:

$$P = 0$$

This signifies that if you have  $A = 1$  (true), the result of NOT operation is going to be 0 (false).

**Truth Table:**

The following table will illustrate the working of NOT operation for all possible inputs of the variable. Below is the truth table for the NOT operation.

A	NOT A (P)
0	1
1	0

Table 3.3: Truth Table for NOT Operation



**Explanation:**

When the input A is 0, the output P is 1. When A is 1 the output value P is 0. A NOT operation performs the negative of the input variable i. e., it gives the opposite value. This operation is important in digital logic design to generate more complex logic functions and verify the functionality of digital circuits.

**3.2.1.2 Construction of Boolean Functions**

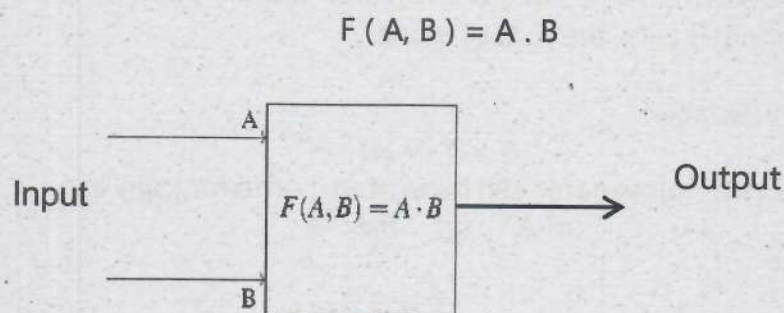
Boolean functions are algebraic statements that describe the relationship between binary variables and logical operations. These functions are particularly important for digital logic design and are employed in formation of various digital circuits, which are the basis of current computers, mobile phones and even simple calculator.

**Understanding Boolean Functions:**

A Boolean function is a function which has a one or more binary inputs and produces a single binary output. The inputs and outputs can only have two values: False (represented by 0) and True (represented by 1). The construction of Boolean functions is done by employing the basic logical operations such as AND, OR and NOT, which connect the inputs to generate the correct output.

**Example 1: Simple Boolean Function**

Consider a Boolean function with two inputs, A and B. We can construct a function F that represents the AND operation:



**Figure 3.2: Simple Boolean Function**

The diagram shown above demonstrates a basic digital circuit, which is an AND gate. The box symbolizes the AND function  $F(A, B) = A \cdot B$ . This box has two inputs A and B. If both A and B are 1, the output will be 1. In any other case, the output will be 0. The input are shown at the entrance to the box, while the output is depicted at the exit of the block. The truth table for this function is as follows:



A	B	F(A, B)
0	0	0
0	1	0
1	0	0
1	1	1

Table 3.4: Truth Table for  $F(A, B) = A \cdot B$

**Example 2:** Now, let us construct a more complex Boolean function with three inputs, A, B, and C:

$$F(A, B, C) = A \cdot B + \bar{A} \cdot C$$

This function uses AND, OR and NOT at the same time. The truth table for this function is as follows:

**Explanation:**

- The parameters A, B, and C are included in the following example as the input columns.
- The results of AND operation between two variable A and B are presented in the column  $A \cdot B$ .
- The column  $\bar{A}$  standing for the NOT operation of A.
- Every value in the column  $\bar{A} \cdot C$  displays the result of AND operation between the values in the Fifth column and the third column.
- The final column  $F(A, B, C)$  shows the output of the Boolean function  $(A \cdot B) + (\bar{A} \cdot C)$

A	B	C	$A \cdot B$	$\bar{A}$	$\bar{A} \cdot C$	$F(A, B, C)$
0	0	0	0	1	0	0
0	0	1	0	1	1	1
0	1	0	0	1	0	0
0	1	1	0	1	1	1
1	0	0	0	0	0	0
1	0	1	0	0	0	0
1	1	0	1	0	0	1
1	1	1	1	0	0	1

Table 3.5: Detailed Truth Table for  $F(A, B, C) = (A \cdot B) + (\bar{A} \cdot C)$

**Usage in Computers:**

There are many uses of Boolean functions in the computers for various operations. Here are some examples of their usage:

- **Arithmetic Operations:** Boolean functions are used in Arithmetical Logic Units (ALUs) of CPUs to perform operations like addition, subtraction, multiplication, and even division.



- **Data Processing:** Boolean functions are used to process binary data in memory and storage devices, ensuring efficient data manipulation and retrieval.
- **Control Logic:** Boolean functions are applied in computers to control various parts of the system's operation to function in co-ordinated manner.



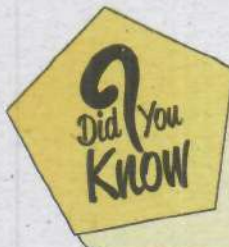
Boolean functions are also present in our everyday devices like cell phones and calculators:

**Cell Phones:** In cell phone processing, when you dial a number, or press a button on a phone, a Boolean function evaluates these inputs as true or false and makes the necessary output.

**Calculators:** Basic calculators use Boolean functions. When you feed it with numbers and the operations to be performed, Boolean logic is used to arrive at the right result.

### Class activity

Consider what do you do with your cell phone or calculator on daily basis. Can you distinguish activities that require logical choices, like entering a password to unlock your smart phone or solving a math problem? Ask your group members how Boolean functions may be utilized in the background.



George Boole, a mathematician who invented Boolean algebra was born in Lincoln, England in the year 1815. His work laid the debate and the basis for future digital revolution and computer science as well as subsequent technologies of the future.

### 3.2.2 Logic Gates and their Functions

Logic gates are physical devices in electronic circuits that perform Boolean operations. Each type of logic gate corresponds to a basic Boolean operation. Examples of the logic gates are:

**AND Gate:** Implements the AND function. It outputs true only when both inputs are True (1)





Figure 3.3: AND Gate

Imagine a simple electronic circuit with an AND gate. If you press two switches (both must be ON), a light bulb will turn on.

- Switch 1: ON (True)
- Switch 2: ON (True)
- Light bulb: ON (True) because both switches are ON.

If either switch is OFF, the light bulb will be OFF.

**OR Gate:** Implements the OR function. It outputs true when at least one input is true.



Figure 3.4: OR Gate

**NOT Gate:** Implements the NOT function. It outputs the opposite of the input. See Figure 3.4

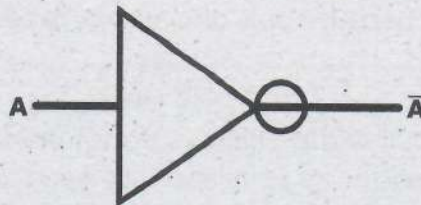


Figure 3.5: NOT Gate

**NAND Gate:** This gate is achieved when an AND gate is combined with a NOT gate. It generates true when at least one of the inputs is false. In other words, it is the inverse of the AND gate, as presented in Figure 3.6.

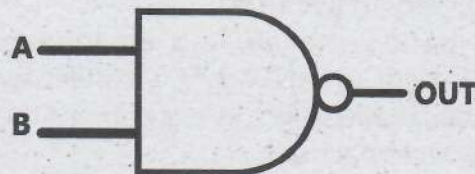


Figure 3.6: NAND Gate



### Example:

Imagine a safety system where an alarm should go on if either one of two sensors detects an issue.

- Sensor 1: No issue (False)
- Sensor 2: Issue detected (True)
- Alarm: ON (True) because one sensor detects an issue.

### XOR Gate:

The XOR (Exclusive OR) gate outputs true only when exactly one of the inputs is true. It differs from the OR gate in that it does not output true when both inputs are true. It is shown in Figure 3.7.



Figure 3.7: XOR Gate

### Example:

Imagine a scenario where you can either play video games or do homework, but not both at the same time.

- Play video games: Yes (True)
- Do homework: No (False)
- Allowed? Yes (True) because only one activity is being done.

### Class activities

Let's make learning these logical functions fun with an activity!

1. **AND Adventure:** Form pairs and give each pair two conditions they need to meet to win a prize (like both wearing a specific color shirt).
2. **OR Options:** Make a list of fun activities. If at least one activity is possible, the class gets extra playtime.
3. **NOT Negatives:** Ask true/false questions and have students shout the opposite answer. For example, "Is the sky green?" Students should shout "No!" (NOT True).
4. Construct a basic circuit using a breadboard, a battery, and LED lights to represent an AND gate. Connect two switches which will serve as, inputs A and B. In this experiment the LED will light up only when both switches are pressed.



### 3.3 Simplification of Boolean Functions

Simplification of Boolean functions is a particularly important process in designing an efficient digital circuit. Such simplified functions require fewer gates making them compact in size, energy efficient and faster than the complicated ones. Simplification means applying of some Boolean algebra rules to make the functions less complicated.

#### Basic Boolean Algebra Rules:

Here are some fundamental Boolean algebra rules used for simplification:

1. **Identity Laws**  
 $A + 0 = A$   
 $A \cdot 1 = A$
2. **Null Laws**  
 $A + 1 = 1$   
 $A \cdot 0 = 0$
3. **Idempotent Laws**  
 $A + A = A$   
 $A \cdot A = A$
4. **Complement Laws**  
 $A + \overline{A} = 1$   
 $A \cdot \overline{A} = 0$
5. **Commutative Laws**  
 $A + B = B + A$   
 $A \cdot B = B \cdot A$
6. **Associative Laws**  
 $(A + B) + C = A + (B + C)$   
 $(A \cdot B) \cdot C = A \cdot (B \cdot C)$
7. **Distributive Laws**  
 $A \cdot (B + C) = (A \cdot B) + (A \cdot C)$   
 $A + (B \cdot C) = (A + B) \cdot (A + C)$
8. **Absorption Laws**  
 $A + (A \cdot B) = A$   
 $A \cdot (A + B) = A$
9. **De Morgan's Theorems**  
 $\overline{A + B} = \overline{A} \cdot \overline{B}$   
 $\overline{A \cdot B} = \overline{A} + \overline{B}$
10. **Double Negation Law**  
 $\overline{\overline{A}} = A$



## Simplification Examples

### Example 1

Simplify the expression  $A + \bar{A} \cdot B$ .

**Solution:**

$$\begin{aligned} A + \bar{A} \cdot B &= (A + \bar{A}) \cdot (A + B) \\ &= 1 \cdot (A + B) \\ &= A + B \end{aligned}$$

(Distributive Law)

(Complement Law)

(Identity Law)

### Example 2

Simplify the expression  $\overline{A \cdot B} + \overline{A} \cdot \overline{B}$ .

**Solution:**

$$\begin{aligned} \overline{A \cdot B} + \overline{A} \cdot \overline{B} &= \overline{A + B} + \overline{A} \cdot \overline{B} \\ &= (\overline{A} + \overline{B}) \\ &= \overline{A + B} \end{aligned}$$

(De Morgan's Theorem)

Since  $\overline{A}$  is already present in  $(\overline{A} + \overline{B})$ , we can use absorption law  
i.e.  $A + (A \cdot B) = A$

### Example 3

Simplify the expression  $(A + B) \cdot (A + \bar{B})$

**Solution:**

$$\begin{aligned} (A + B) \cdot (A + \bar{B}) &= A \cdot (A + \bar{B}) + B \cdot (A + \bar{B}) \\ &= A + A \cdot \bar{B} + B \cdot \bar{B} \\ &= A + A \cdot B \\ &= A \cdot (1 + B) \\ &= A \cdot 1 \\ &= A \end{aligned}$$

(Distributive Law)

(Absorption Law)

(Identity Law)

(Distributive Law)

(Null Law)

(Identity Law)

### Example 4

Simplify the expression  $\overline{A + B} \cdot (A + \bar{B})$

**Solution:**

$$\begin{aligned} \overline{A + B} \cdot (A + \bar{B}) &= (\overline{A \cdot B}) \cdot (A + \bar{B}) \\ &= A \cdot \bar{B} \cdot A + A \cdot \bar{B} \cdot \bar{B} \\ &= A \cdot \bar{B} + A \cdot \bar{B} \\ &= A \cdot \bar{B} \end{aligned}$$

(De Morgan's Theorem)

(Distributive Law)

(Idempotent Law)

(Identity Law)



### 3.4. Creating Logic Diagrams

The logic diagrams depict the working of a digital circuit through symbols that represent to its individual logic gates. To create a logic diagram:

- Find out the logic gates needed for the Boolean function.
- Arrange the gates to perform the operations as defined by the function of the circuit.
- Connect the inputs and the output of the gates correctly.

To summarize, knowledge of Boolean algebra and logic gates is crucial when it comes to the creation and study of digital circuits. If students understand those concepts, they can build efficient and effective digital systems.

### 3.5. Application of Digital Logic

Digital logic is an essential aspect for the functioning of several modern electronic systems, such as computers, smart phones, and other digital gadgets. Digital logic optimize in many ways in order to create and enhance circuits meant to perform various tasks. Two important applications of digital logic are the design of adder circuits and the use of Karnaugh maps for function simplification.

#### 3.5.1 Half-adder and Full-adder Circuits

Adder circuits are widely used in the digital circuits to perform arithmetic calculations. There are two general forms of adder circuits known as half-adders and full adders.

##### 3.5.1.1 Half-adder Circuits

A half adder is a basic circuitry unit that performs addition of two single-bit binary digits. It has two inputs, usually denoted as A and B, and two outputs: the sum (S) and the carry (C).

**Truth Table for Half-adder:**

A	B	Sum (S)	Carry (C)
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

Table 3.6: Truth Table for Half-adder

Boolean Expressions for Half-adder:

$$S = A \oplus B$$

$$C = A \cdot B$$

In this case the symbol  $\oplus$  represents the XOR operation. The sum output is high when only one of the inputs is high, while the carry output is high when both inputs are high.



## Boolean Expressions:

$$\text{Sum} = A \oplus B$$

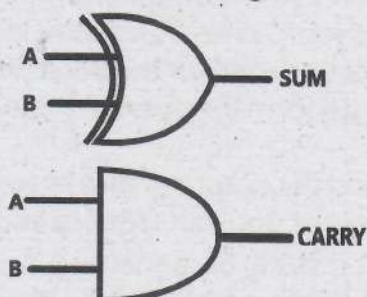


Table 3.8: Half-Adder Circuit

### 3.5.1.2 Full-adder Circuits

A full-adder is a more complex circuit that adds three single-bit binary numbers: two bits that belong to the sum and a carry bit from a previous addition. It has three inputs, denoted as A, B, and  $C_{in}$  (carry input), and two outputs: called the sum (S) and the carry ( $C_{out}$ ) with both being integer values.

A	B	$C_{in}$	Sum (S)	Carry ( $C_{out}$ )
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

Table 3.7: Truth Table for Full-adder

## Boolean Expressions:

$$\text{Sum} = A \oplus B \oplus C_{in}$$

$$\text{Carry} = (A \cdot B) + (C_{in} \cdot (A \oplus B))$$

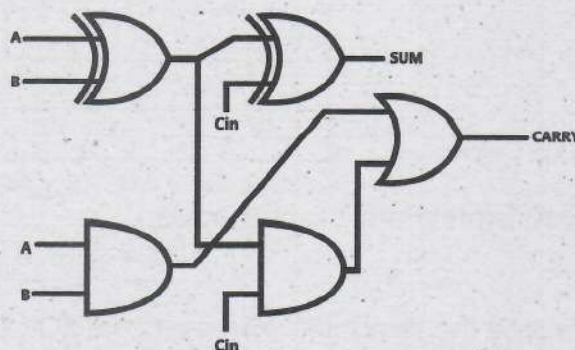


Table 3.9: Half-Adder Circuit



The sum output is high if the number of high inputs is odd whereas the carry output is high if the number of high inputs is at least 2.

### 3.5.2 Karnaugh Map( K-Map)

A Karnaugh map (K-map) is a graphical representation which can be used to solve Boolean algebra expressions and minimize a logic function where algebraic computations are not employed. It is a technique in which the truth value of Boolean function is plotted to enable the identification of patterns and to perform term combining for simplification.

Minterm	Variables Combination	Minterm Expression
m0	A= 0, B= 0,C= 0	$\overline{A}\overline{B}\overline{C}$
m1	A= 0, B= 0,C= 1	$\overline{A}\overline{B}C$
m2	A= 0, B= 1,C= 0	$\overline{A}B\overline{C}$
m3	A= 0, B= 1,C= 1	$\overline{A}BC$
m4	A= 1, B= 0,C= 0	$A\overline{B}\overline{C}$
m5	A= 1, B= 0,C= 1	$A\overline{B}C$
m6	A= 1, B= 1,C= 0	$AB\overline{C}$
m7	A= 1, B= 1,C= 1	$ABC$

Table 3.8: Possible Minterms for A,B and C

#### 3.5.2.1 Structure of Karnaugh Maps

A K-map is a matrix where each square is a cell, which corresponds to a positioned combination. These cells are filled with '1' or '0' in reference to the truth table of the Boolean function. The size of the K-map depends on the number of variables:

- 2 Variables: 2x2 grid
- 3 Variables: 2x4 grid
- 4 Variables: 4x4 grid least
- 5 Variables: 4x8 grid (less common for manual simplification)

Every cell in the K-map represents a minterm, and the cells in each row of the K-map differ by only one bit at any particular position, following the gray code sequence.

#### 3.5.2.2 Minterms in Boolean Algebra

In Boolean algebra, a minterm is a particular product term whereby every variable of the function is present in either 1 its true form or its complement. Each minterm corresponds to one and only one set of variable values that makes the Boolean function equal to true or 1.



Minterm Notation For a Boolean function with variables A, B and C:

The minterm where  $A = 1, B = 0$  and  $C = 1$  is written as  $A\bar{B}C$ .

Consider a Boolean function  $F(A,B,C)$ . The possible minterms for this function are:  
Possible Minterms for A,B,C

### 3.5.2.3 Creating Karnaugh Maps

To create a K-map, follow these steps:

1. Create a grid based on the number of variables that exists in the system.
2. Let us complete the grid using the output values in the truth table.
3. Arrange the 1s in the grid in the largest possible groups of size 1, 2, 4, 8 and so on. Every group must have one or more 1s, must be a power of two, and they must be in a continuous rows or columns.

#### Example: Simplifying a Boolean Expression with a K-map

To simplify the Boolean expression  $A \cdot \bar{B} + \bar{A} \cdot B + A \cdot B$  using a Karnaugh map (K-map):

**1. Expression:**  $A \cdot \bar{B} + \bar{A} \cdot B + A \cdot B$

#### Step 1: Draw the K-map Grid

For two variables A and B:

	$\bar{B} = 0$	$B = 1$
$\bar{A} = 0$	0	1
$A = 1$	1	1

#### Step 2: Fill in the K-map

Determine the output for each combination of A and B based on the expression:

- For  $A = 0$  and  $B = 0$ :  $F = \bar{A} \cdot \bar{B} + \bar{A} \cdot B + A \cdot B = 1 \cdot 0 + 0 \cdot 0 + 0 \cdot 0 = 0$
- For  $A = 0$  and  $B = 1$ :  $F = \bar{A} \cdot \bar{B} + \bar{A} \cdot B + A \cdot B = 0 \cdot 0 + 1 \cdot 1 + 0 \cdot 1 = 1$
- For  $A = 1$  and  $B = 0$ :  $F = \bar{A} \cdot \bar{B} + \bar{A} \cdot B + A \cdot B = 1 \cdot 1 + 0 \cdot 0 + 1 \cdot 0 = 1$
- For  $A = 1$  and  $B = 1$ :  $F = \bar{A} \cdot \bar{B} + \bar{A} \cdot B + A \cdot B = 1 \cdot 0 + 0 \cdot 1 + 1 \cdot 1 = 1$

#### Step 3: Group the 1s in the K-map

Group adjacent 1s to simplify the expression

	$\bar{B} = 0$	$B = 1$
$\bar{A} = 0$	0	1
$A = 1$	1	1



**From the K-map, we can form the groups:**

1. Group of two 1s in the second column:  $A \cdot B + A \cdot \bar{B}$   
 $A \cdot B + A \cdot \bar{B} = (A + A) \cdot B = 1 \cdot B = B$
2. Group of two 1s in the second row:  $A \cdot B + \bar{A} \cdot B$   
 $A \cdot B + \bar{A} \cdot B = (B + B) \cdot A = 1 \cdot A = A$

**Final Simplified Expression**

$$F(A, B) = B + A$$

**Practical Usage:**

Karnaugh maps are extensively used in digital circuit design to minimize the number of gates needed for a given function. This leads to circuits that are faster, cheaper, and consume less power.

### Class Activity

Activity: Construct a digital circuit that includes both half-adders and full-adders to add two 4-bit binary numbers. Create the truth tables, Boolean expressions, and circuit diagrams for each step.

### Summary

- Digital systems are the basis of the present-day electronics and computing. They process digital data in form of '0' and '1'.
- Analog signals are continuous time varying signal.
- ADC (Analog to Digital Converter) is the process of converting the continuous signals into discrete signals that can be processed by digital devices for example computers and smart phones.
- DAC (Digital to Analog Converter) converts the digital signal back to the analog signal.
- Digital logic is the basis of all digital systems. This is the technique we use to process digital information in the form of binary numbers.
- Boolean algebra is a sub-discipline of mathematics based on operations involving binary variables.
- In the case of AND operation the output is 1 only when both input values are 1. Otherwise, the output is 0.
- In an OR gate, the result is 0 only when both the input values are 0. Otherwise, the output is 1.
- The NOT operation the simplest logical operation in Boolean algebra, which accept a single binary inputs and gives its opposite as the outputs.
- Boolean functions are mathematical expressions that represent logical operations involving binary variables.
- A crucial element of digital circuit design is the logic diagram, which represents the structure of the circuit by showing connections between



logic gates.

- Adder circuits are widely used in the digital electronic systems with the principal application in arithmetic operations.
- A half-adder is a digital circuit used to compute the addition of two single-bit binary numbers.
- A full-adder is a more complex circuit that adds three single-bit numbers: two main bits and a carry bit from a previous addition.
- A Karnaugh map (K-map) is a graphic aid that is employed in simplification of Boolean expressions and minimizing logic functions without the use of complex algebraic operations.
- A minterm in Boolean algebra is a specific product (AND) form of a Boolean expression that includes all of the function's variables, either in their normal or complemented form.

## EXERCISE

### Multiple- Choice Questions (MCQs)

1. Which of the following Boolean expressions represents the OR operation?  
(a)  $A \cdot B$  (b)  $A + B$  (c)  $A$  (d)  $A \oplus B$
2. What is the dual of the Boolean expression  $A \cdot 0 = 0$ ?  
(a)  $A + 1 = 1$  (b)  $A + 0 = A$  (c)  $A \cdot 1 = A$  (d)  $A \cdot 0 = 0$
3. Which logic gate outputs true only if both inputs are true?  
(a) OR gate (b) AND gate (c) XOR gate (d) NOT gate
4. In a half-adder circuit, the carry is generated by which operation?  
(a) XOR operation (b) AND operation  
(c) OR operation (d) NOT operation
5. What is the decimal equivalent of the binary number 1101?  
(a) 11 (b) 12 (c) 13 (d) 14

### Short Questions

1. Define a Boolean function and give an example.
2. What is the significance of the truth table in digital logic?
3. Explain the difference between analog and digital signals.
4. Describe the function of a NOT gate with its truth table.
5. What is the purpose of a Karnaugh map in simplifying Boolean expressions?

### Long Questions

1. Explain the usage of Boolean functions in computers.
2. Describe how to construct a truth table for a Boolean expression with an example.



3. Describe the concept of duality in Boolean algebra and provide an example to illustrate it.
4. Compare and contrast half-adders and full-adders, including their truth tables, Boolean expressions, and circuit diagrams.
5. How do Karnaugh maps simplify Boolean expressions? Provide a detailed example with steps.
6. Design a 4-bit binary adder using both half-adders and full-adders. Explain each step with truth tables, Boolean expressions, and circuit diagrams.
7. Simplify the following Boolean function using Boolean algebra rules:

$$F(A, B) = A \cdot B + A \cdot \overline{B}$$

8. Use De Morgan's laws to simplify the following function:

$$F(A, B, C) = \overline{A + B + AC}$$

9. Simplify the following expressions

- (a)  $A + B \cdot (A + B)$
- (b)  $(A + \overline{B}) \cdot (\overline{A} + B)$
- (c)  $A + \overline{A} \cdot (\overline{B} + C)$
- (d)  $\overline{A \cdot B} + A \cdot B$
- (e)  $(A \cdot B) + (\overline{A} \cdot \overline{B})$



# UNIT 4

## System Troubleshooting

### Student Learning Outcomes

**By the end of this chapter, you will be able to:**

1. Explain the importance of troubleshooting in maintaining and operating computer systems effectively.
2. Describe how systematic troubleshooting helps prevent and resolve computer issues.
3. Demonstrate the ability to systematically troubleshoot computer issues.
4. Apply basic troubleshooting techniques, including Restarting a computer, Identifying and addressing basic software hardware issues.
5. Identify and resolve common computer issues, such as Application freezing, unresponsive peripherals, Software conflicts and operating system crashes.
6. Implement strategies for maintaining a safe and organized computer workspace.
7. Understand the importance of data backups and apply methods for effective data protection.
8. Diagnose and address hardware issues, including hardware failures like RAM or hard drive issues. Performing component replacements and upgrades.
9. Recognizing and addressing security threats such as malware infections.
10. Apply best practices for maintaining system security by updating operating systems, creating and managing strong passwords, recognizing and addressing malware threats.
11. Use built-in help features and internet resources effectively to troubleshoot complex issues.
12. Communicate solutions and troubleshooting steps clearly to assist peers and staff with computer-related problems.
13. Transfer troubleshooting knowledge to help others and collaborate effectively in solving computer issues.



## Introduction

System troubleshooting is a vital skill for keeping computers, machines, and other equipment running smoothly. When things go wrong, troubleshooting helps identify the problem and find a quick solution, preventing issues like downtime, reduced productivity, and potential damage. For instance, if your computer suddenly stops working, knowing how to troubleshoot can help you fix it without needing costly professional help. This chapter will guide you through a systematic process of troubleshooting, covering essential steps such as identifying problems, testing theories, implementing solutions, and ensuring the system is fully functional again. By mastering these techniques, you'll be able to maintain the reliability and efficiency of any system you work with.

### 4.1 System Troubleshooting

Troubleshooting is essential for maintaining the smooth operation of systems, whether they are computers, machines, or other types of equipment. When something goes wrong, troubleshooting helps identify the problem and find a solution quickly. For example, if your computer suddenly stops working, knowing how to troubleshoot can help you get it running again without needing to call for expensive professional help.

#### 4.1.1 Systematic Process of Troubleshooting

The troubleshooting process involves several steps that help you systematically identify and fix problems. These steps ensure that you don't overlook any potential issues and that you solve the problem efficiently.

A systematic approach to troubleshooting involves the following steps:

1. Identify Problem
2. Establish a Theory of Probable Cause
3. Test the Theory to Determine the Cause
4. Establish a Plan of Action to Resolve the Problem
5. Implement the Solution
6. Verify Full System Functionality
7. Document Findings, Actions, and Outcomes

#### Tidbits

**Tech Detective Work:** Troubleshooting is like being a detective for technology. Just like a detective solves mysteries, you solve tech problems by following clues and gathering evidence!



#### **4.1.1.1 Identify Problem**

The first step in troubleshooting is to identify the problem. This means recognizing that something is not working as it should. For example, if you press power button and your laptop does not turn on, the problem is clear that it won't start.

#### **4.1.1.2 Establish a Theory of Probable Cause**

Once you have identified the problem, the next step is to come up with a theory about what might be causing it. This involves thinking about what could have gone wrong. For example, if your laptop does not turn on, possible causes might be a dead battery, a faulty power cord, or an internal hardware issue.

#### **4.1.1.3 Test the Theory to Determine the Cause**

After establishing a theory, you need to test it to see if it is correct. This involves checking if the suspected cause is actually the reason for the problem. For example, if you think the laptop's battery is dead, you can test this theory by plugging in the power cord and seeing if the computer turns on.

#### **4.1.1.4 Establish a Plan of Action to Resolve the Problem**

If your test confirms the cause of the problem, the next step is to come up with a plan to fix it. This means deciding what steps you need to take to resolve the issue. For example, if the problem is a dead battery, your plan of action might be to replace the battery or keep the laptop plugged in until you can get a new one.

#### **4.1.1.5 Implement the Solution**

Once you have a plan, you need to put it into action. This means doing whatever is necessary to fix the problem. For example, if your plan is to replace the battery, you would buy a new battery and install it in your laptop.

#### **4.1.1.6 Verify Full System Functionality**

After implementing the solution, you need to check to make sure that the problem is fully resolved and the system is working properly again. For example, once you replace the battery, you should check to see if the laptop turns on and operates as expected without plugging in the power cord.

#### **Tidbits**

Instant Fix: Sometimes, the quickest fix for a computer problem is to restart it. This is like giving the computer a nap—sometimes it just needs a short break to work properly again.



#### **4.1.1.7 Document Findings, Actions, and Outcomes**

The final step is to document everything you did during the troubleshooting process. This includes what the problem was, what you thought was causing it, what you did to fix it, and the outcome. This documentation is important for future reference and can help you or others troubleshoot similar problems more efficiently in the future. For example, you would write down that the laptop wouldn't turn on due to a dead battery, that you replaced the battery, and that the laptop is now working properly.

By following the above steps, you can troubleshoot problems systematically and effectively, ensuring that systems continue to operate smoothly and efficiently.

#### **4.1.2 Importance of Troubleshooting in Computing Systems**

Troubleshooting is very important in computing systems because it helps keep our computers, software, and networks running smoothly. When something goes wrong with a computer system, it can disrupt our work, cause data loss, or even lead to security issues. By knowing how to troubleshoot computing systems, we can quickly find and fix problems, ensuring that everything works as it should.

##### **4.1.2.1 Preventing Downtime**

Downtime occurs when a computer system is not operational. This can be very costly, especially in businesses that rely on their systems to operate efficiently. When a system is down, employees may not be able to work, leading to lost productivity and revenue. With the help of troubleshooting, we identify and resolve the system problems in very short time which facilitate to reduce the possibilities of system downtime.

##### **4.1.2.2 Ensuring Data Integrity**

Data integrity means ensuring that data is accurate and reliable. Problems like software bugs or hardware failures can corrupt data, leading to incorrect information being stored or processed. Troubleshooting helps identify the source of data corruption and prevent it from happening again, ensuring that data remains accurate and reliable.

##### **4.1.2.3 Improving Security**

Computer systems are often targets for cyber-attacks. Troubleshooting can help identify vulnerabilities and security breaches, allowing for quick action to protect the system. This is important for maintaining the confidentiality, integrity, and availability of data.

##### **4.1.2.4 Enhancing Performance**

Sometimes, computer systems do not perform as efficiently as they should. Troubleshooting can identify the reasons for slow performance, such as insufficient memory, software conflicts, or hardware malfunctions. By resolving these issues, you can improve the overall performance of the system.



#### 4.1.2.5 Extending Equipment Life

Regular troubleshooting and maintenance can help extend the life of computer equipment. By identifying and fixing small issues before they become big problems, you can prevent unnecessary wear and tear on the system.

#### 4.1.2.6 Saving Costs

**Real-World Impact:** Effective troubleshooting in businesses helps prevent costly downtime and maintains productivity, showing how important these skills are in the real world. Effective troubleshooting can save money by reducing the need for expensive repairs or replacements. By identifying and resolving issues early, you can avoid costly downtime and prolong the life of your

**Real-World Impact:** Effective troubleshooting in businesses helps prevent costly downtime and maintains productivity, showing how important these skills are in the real world.

#### Tidbits

**Example:** If a printer is not working properly, troubleshooting might reveal a simple paper jam that can be fixed easily, rather than needing to replace the entire printer.

#### 4.1.1.7 Enhancing User Experience

When computer systems work well, users have a better experience. They can complete their tasks efficiently without encountering frustrating issues. Troubleshooting helps ensure that systems are reliable and user-friendly.

**Example:** If an application keeps crashing, troubleshooting can identify if the problem is due to software bugs or compatibility issues. Fixing the issue can improve the user experience, making the application more stable and enjoyable to use.

Troubleshooting is an essential skill in computing systems. It helps prevent downtime, ensure data integrity, improve security, enhance performance, extend equipment life, save costs, and provide a better user experience. By understanding and applying troubleshooting techniques, we can keep our computing systems running smoothly and efficiently.

#### Activity Task Details:

#### Class activity

1. **Introduction:** Briefly explain the importance of troubleshooting in computer systems.
2. **Discussion:** Divide students into small groups and provide each group with a printed troubleshooting flowchart.
3. **Task:** Have each group discuss a scenario where a computer is not turning on. Using the flowchart, they should identify potential problems and suggest solutions. For example, checking if the power cable is plugged in and if the power button is functioning.
4. **Presentation:** Each group presents their findings and solutions to the class.



## 4.2 Troubleshooting Strategies

Understanding basic troubleshooting strategies for software and hardware issues can help keep your computing systems running smoothly. By identifying common problems and knowing simple solutions, you can resolve issues quickly and efficiently, ensuring minimal disruption to your work or activities.

### 4.2.1 Basic Software-Related Issues

#### 4.2.1.1 Common Software Issues and Solutions

**Issue: Application Freezing** - An application freezing means that a program stops responding and you cannot use it. This is a common problem and can usually be fixed with a few simple steps:

**Solution:** Try pressing Ctrl + Alt + Delete to open the Task Manager. Find the unresponsive application, select it, and click "End Task." This will force the application to close. If the problem persists, consider reinstalling the application or checking for updates.

**Issue: Unresponsive Peripherals** - Peripherals are external devices like keyboards, mice, and printers. Sometimes, these devices can stop responding due to software issues.

**Solution:** First, check the connections to make sure they are secure. If the device is still unresponsive, try unplugging it and then plugging it back in. Updating the drivers for the device can also help.

#### 4.2.1.2 Restarting and Shutting Down

**Issue: Importance of Restarting a Computer** - Restarting a computer can fix many software issues. It clears the memory, stops background processes, and gives the system a fresh start.

**Issue: Using the Power Button Effectively** - The power button can be used to shut down or restart a computer when it is not responding to normal commands.

**Solution:** Press and hold the power button for a few seconds to force the computer to shut down. This should only be used as a last resort because it can cause data loss if programs are not properly closed.



**Restarting the Computer:** Restarting a computer can fix up to 50% of all software issues. This is because a reboot clears the system's memory and stops processes that might be causing conflicts.



## Tidbits

The Power of Documentation: Keeping track of your troubleshooting steps is like writing a diary of your adventures. It helps you remember what worked and what didn't, making future problems easier to solve.

### 4.2.2 Basic Hardware-Related Issues

#### 4.2.2.1 Common Hardware Issues and Solutions

**Issue: Cable Disconnection** - Loose or disconnected cables are a common hardware issue that can cause devices to stop working.

**Issue: Overheating** - Overheating can cause a computer to slow down, freeze, or shut down unexpectedly.

**Issue: Peripheral Devices** - Peripheral devices like keyboards and monitors can have various issues, from not being recognized by the computer to not working correctly.

## Tidbits

**Cool Tools:** Modern troubleshooting involves using special tools like memory diagnostic apps (e.g., MemTest86) and hard drive health checkers (e.g., CrystalDiskInfo). These tools are like having superpowers that can see inside your computer's brain! problems by following clues and gathering evidence!

#### 4.2.2.2 Maintaining a Safe Workspace

**Issue: Cable Management** - Proper cable management can prevent accidental disconnections and reduce the risk of tripping or damaging cables.

**Solution:** Use cable ties or organizers to keep cables neat and out of the way. Labeling cables can also help identify them easily.

**Cable Management:** Good cable management is crucial. It's like organizing your school supplies; when cables are neatly arranged, it's easier to find and fix issues. Plus, it helps prevent accidental disconnections.

**Example:** In an office, using cable ties to bundle cables together can prevent them from getting tangled and make it easier to identify which cable goes to which device.

## Tidbits

**Cable Management:** Good cable management is crucial. It's like organizing your school supplies; when cables are neatly arranged, it's easier to find and fix issues. Plus, it helps prevent accidental disconnections.



**Issue: Proper Ventilation** - Proper ventilation is crucial to prevent overheating and ensure the computer runs efficiently.

**Solution:** Place the computer in a well-ventilated area, away from walls and other obstructions. Regularly clean the vents and fans to remove dust buildup.

**Example:** Keeping a desktop computer on a desk with good airflow around it can help prevent overheating and keep it running smoothly.

#### Class activity

##### Workspace Management

**Objective:** Learn how to maintain a safe and organized computer workspace.

**Required Material:** Computers, cable ties, labels, ventilated computer stands.

**Activity Type:** Individual

##### Activity Task Details:

1. **Introduction:** Discuss the importance of a well-organized workspace for preventing hardware issues.
2. **Task:** Each student will organize their workspace by managing cables with ties and labels, and ensuring their computer is properly ventilated using stands. For example, tying together cables to prevent them from tangling and ensuring the computer is not placed in a confined space to prevent overheating.

### 4.2.3 Hardware Diagnosis and Maintenance

#### 4.2.3.1 Recognizing Hardware Failures

Recognizing hardware failures is necessary for maintaining a computer system's functionality. Here are some common symptoms and diagnostic techniques of RAM or Hard Drive Failures:

**Issue: RAM Failures** - Common signs of RAM issues include frequent system crashes, Blue Screens Of Death (BSOD), and poor performance. The computer may also fail to boot or restart randomly.

**Solution: RAM Diagnostic Tools** - Use built-in tools like Windows Memory Diagnostic or third-party applications like MemTest86 to check for RAM issues.

Did You Know

**Memory Failures:** Faulty RAM can cause system crashes and data corruption. RAM errors can account for up to 10% of all computer crashes and Blue Screens Of Death (BSOD).  
**Reference:** PCMag - Troubleshooting RAM Issues



**Issue: Hard Drive Failures** - Symptoms of hard drive failures include strange noises (like clicking), slow performance, frequent crashes, and corrupted files. The computer may also fail to boot or display error messages about the disk.

**Solution: Hard Drive Diagnostic Tools** - Use tools like SMART (Self-Monitoring, Analysis, and Reporting Technology) status checks, or software like CrystalDiskInfo, to monitor hard drive health.

#### 4.2.3.2 Component Replacements and Upgrades

Upgrading or replacing hardware components can significantly improve your computer's performance and extend its lifespan.

**Upgrading RAM:** To upgrade RAM, first determine the type and maximum capacity your motherboard supports. Purchase compatible RAM sticks, power off your computer, open the case, and insert the new RAM into the empty slots.

**Example:** If your computer is slow while multitasking (running multiple applications at a time), adding more RAM can help improve its performance.

**Replacing a Hard Drive:** To replace a hard drive, back up your data, purchase a compatible drive (that can work in your computer), power off your computer, open the case, disconnect the old drive, and connect the new one. After installing the new drive, you will need to reinstall the operating system and restore your data from the backup.

**Example:** If your hard drive is failing, replacing it with a new one can prevent data loss and restore your computer's functionality

#### Tidbits

**Space Saver:** Keeping your computer's storage clean by deleting unnecessary files is like making space in your room. The more organized your files are, the faster your computer will run—just like a tidy room is easier to navigate.

#### 4.2.4 Security and Maintenance

Understanding and applying regular maintenance and security measures are essential for the proper and continued performance of a system. Using the following security, maintenance and troubleshooting techniques, you can effectively maintain and enhance the performance and security of your computing systems.



### Class activity

#### Activity : Common Computer Issues

**Objective:** Recognize and resolve common computer issues.

**Required Material:** Computers, list of common issues, troubleshooting guides.

**Activity Type:** Individual

#### Activity Task Details:

1. **Introduction:** Briefly explain common computer issues like application freezing and unresponsive peripherals.
2. **Task:** Provide students with a list of common issues and troubleshooting guides.

**Hands-on Practice:** Each student will troubleshoot the issues on their computer and document the steps they took to resolve them. For example, if the mouse is unresponsive, check the USB connection or replace the batteries.

### Class activity

#### Activity : Security Practices

**Objective:** Learn and apply basic security practices.

**Required Material:** Computers, internet access, security software (e.g., antivirus).

**Activity Type:** Individual

#### Activity Task Details:

1. **Introduction:** Discuss common security threats and the importance of strong passwords and software updates.
2. **Task:** Each student will create a strong password for their computer, run a security scan using antivirus software, and update their operating system. For example, creating a password with a mix of letters, numbers, and symbols, and using antivirus software to scan for malware.

**Documentation:** Students will document the steps they took and the outcomes.

#### 4.2.4.1 Maintaining Software

Keeping software up to date and resolving a conflict is essential for security and performance.

**Installing Updates and Software Patches:** Regularly installing updates and patches ensures that your software is protected against vulnerabilities and performs optimally.



**Example:** Updating your operating system and applications can protect your computer from security threats and fix bugs that cause crashes.

**Resolving Software Conflicts:** Identify and uninstall conflicting software, reinstall or update the affected applications, and check for compatibility issues.

**Example:** If two applications are causing system instability, removing one or updating both to the latest versions can resolve the conflict.

Did You Know

**The Power of Updates:** Some updates, like those for operating systems or antivirus software, can be essential for security. For instance, the WannaCry ransomware attack in 2017 exploited a vulnerability in older Windows systems, which had been patched in a security update.

**Reference:** [BBC News - WannaCry Ransomware Attack](#)

#### 4.2.4.2 Addressing Security Threats

Threats protecting your computer from security threats are important for maintaining data integrity and privacy.

**Identifying and Removing Malware Infections:** Use antivirus software to scan for and remove malware. Regularly update the antivirus definitions and perform full system scans.

**Example:** Running a full system scan with updated antivirus software can help detect and remove malware that slows down your computer or steals your data.

**Applying Operating System Updates for Security:** Installing operating system updates is essential for protecting your computer from newly discovered security vulnerabilities.

**Example:** Regularly updating your operating system can prevent hackers from exploiting security flaws to gain access to your system.

**Creating and Managing Strong Passwords:** Use a combination of upper (A-Z) and lower-case (a-z) letters, numbers (0-9), and special characters ( , \$ , % , & , \* , @ etc.) to create strong passwords. Change passwords regularly and use a password manager to keep track of them.

**Example:** Creating a strong password for your online accounts can protect you from unauthorized access and identity theft.



## 4.2.5 Data Management and Backups

Effective data management and regular backups help in free up resources, improve efficiency, and ensure data security. Here's how these practices can be beneficial:

**Data Management and Backups** mean storing, and organizing data so it is easy to find and use. It helps make sure the data is available, accurate, and ready when needed. Regular backups involve making copies of data regularly to ensure it can be recovered if it is lost, damaged, or during a disaster. These strategies are necessary for keeping data safe and ensuring it can always be restored.

### 4.2.5.1 Managing Storage Space

Management of storage space is one of the key requirements for data management. It is important to keep your computer running smoothly and efficiently. Here is how you perform it:

**Deleting Unnecessary Files:** Regularly review your files and delete those you no longer need. This can include old documents, downloaded files, and temporary files.

**Example:** If your computer is running out of space, go through your download folder and delete files you no longer need. This can free up a significant amount of space.

**Moving Files to Free Up Disk Space:** Transfer large files, such as videos and photos, to an external storage device or cloud storage to free up space on your computer's internal drive.

**Example:** Moving a collection of vacation photos to an external hard drive can free up gigabytes of space on your main drive, improving your computer's performance.

### 4.2.5.2 Data Backup Methods

Backing up data is essential to prevent data loss in case of hardware failure or other issues. Here are some common methods:

**Using External Storage Devices:** Use external hard drives or USB flash drives to back up important files. This provides a physical copy of your data that you can easily access and store safely.

**Example:** Copying your important documents and photos to an external hard drive ensures that you have a backup in case your computer's hard drive fails.

**Utilizing Cloud Solutions:** Use cloud storage services like Google Drive,



Dropbox, or OneDrive to back up your data online. This allows you to access your files from anywhere with an internet connection.

**Example:** Saving your school projects to Google Drive means you can access them from any computer, even if your personal device is unavailable or damaged.

#### 4.2.6 Using Resources for Troubleshooting

When you encounter issues, there are many resources available to help you troubleshoot effectively.



**Data Backup:** It's estimated that 60% of people have never backed up their data. Regular backups can protect against data loss from hardware failures, accidental deletions, or malware attacks.

**Reference:** Backing Up Your Data - National Cyber Security Centre

**Built-in Help Features:** Most operating systems and software applications include built-in help features or guides that provide solutions to common problems.

**Example:** If your printer is not working, you can use the built-in troubleshooting guide in your computer's settings to find and fix the issue.

**Internet Resources:** Use online resources such as forums, tutorials, and FAQs to find solutions to more complex problems. Websites like Stack Exchange, Reddit, and YouTube are valuable for troubleshooting help.

**Example:** If you are experiencing a software error, searching the error message on Google can lead you to forums where others have shared solutions.

#### 4.1.7 Assisting Others

Helping others with their computer problems can reinforce your troubleshooting skills and build a collaborative learning environment.

##### 4.1.7.1 Communication and Collaboration

**Importance of Effective Communication in Troubleshooting:** Clearly explain the issue and your troubleshooting steps when assisting others. Listen to their descriptions and ask questions to gather more information.

**Example:** When helping a friend with a software problem, ask them to describe the error message and the actions they took before the issue occurred.

**Collaborating with Peers and Staff to Solve Problems:** Work together with classmates, teachers, or IT staff to troubleshoot issues. Sharing knowledge and experiences can lead to faster and more effective solutions.

**Example:** Collaborating with a peer who has more experience with a particular software can help you both learn new troubleshooting techniques.



### Class activity

#### Collaborative Troubleshooting

##### Activity Task Details:

1. **Introduction:** Explain the value of using online resources and collaboration in troubleshooting.
2. **Task:** Provide groups with a list of complex computer issues.
3. **Research and Solution:** Each group will research solutions using built-in help and internet resources, then apply the solutions to resolve the issues. For example, if a computer is running slow, research potential causes and solutions such as checking for malware or clearing temporary files.

**Presentation:** Groups will present their solutions and the resources they used to the class.

#### 4.7.2.2 Sharing Troubleshooting Knowledge

**Transferring Troubleshooting Skills to Assist Others:** Share your troubleshooting experiences and solutions with others. Create guides or tutorials to help your peers understand how to fix common issues.

**Example:** After resolving a tricky software installation problem, you could write a step-by-step guide and share it with your classmates, making it easier for them to handle similar issues in the future.



**Cooling and Overheating:** Computers can overheat if their cooling systems fail. High temperatures can reduce a CPU's lifespan by up to 50%. Proper cooling and regular cleaning can significantly extend a computer's life.

**Reference:** Tom's Hardware - How Overheating Affects CPUs

### Summary

- Troubleshooting is very important for maintaining a smooth operation of systems like computers and machines.
- Troubleshooting helps identify and resolve problems quickly to prevent downtime and system damage.
- **Systematic Process of Troubleshooting**
  - **Identify Problem:** Recognize and define the issue (e.g., a computer not turning on).
  - **Establish a Theory of Probable Cause:** Develop ideas about what might be causing the problem (For example, dead battery, faulty power cord).



- **Test the Theory:** Check if the suspected cause is correct (For example, testing with a new power cord).
- **Establish a Plan of Action:** Create a plan to fix the issue (e.g., replacing the battery).
- **Implement the Solution:** Apply the fix according to the plan (e.g., installing a new battery).
- **Verify Full System Functionality:** Ensure the problem is fully resolved and the system works properly.
- **Document Findings, Actions, and Outcomes:** Record the troubleshooting process and results for future reference.
- **Troubleshooting Strategies**
  - **Basic Software-Related Issues:**
    - Handle unresponsive applications and peripherals.
    - Use restarting and shutting down methods effectively.
  - **Basic Hardware-Related Issues:**
    - Address cable disconnections and overheating.
    - Troubleshoot peripheral devices and maintain a safe workspace.
  - **Hardware Diagnosis and Maintenance:**
    - Recognize symptoms of RAM and hard drive failures.
    - Perform component replacements and upgrades.
- **Security and Maintenance**
  - **Maintaining Software:** Install updates and resolve software conflicts.
  - **Addressing Security Threats:** Use antivirus software, apply OS updates, and manage passwords.
- **Data Management and Backups**
  - **Managing Storage Space:** Delete unnecessary files and move files to free up space.
  - **Data Backup Methods:** Use external storage devices and cloud solutions for regular backups.
- **Using Resources for Troubleshooting**
  - **Built-in Help Features:** Utilize system help guides and troubleshooting tools.
  - **Internet Resources:** Search forums, tutorials, and FAQs for solutions.



- **Assisting Others**

- **Communication and Collaboration:** Clearly explain issues and collaborate with others for solutions.
- **Sharing Troubleshooting Knowledge:** Create guides and share solutions to assist peers.

## EXERCISE

### Multiple Choice Questions (MCQs)

1. What is the first step in the systematic process of troubleshooting?  
a) Establish a Theory of Probable Cause   b) Implement the Solution  
c) Identify Problem   d) Document Findings, Actions, and Outcomes
2. Why is effective troubleshooting important for maintaining systems?  
a) It helps save money on repairs  
b) It prevents the need for professional help  
c) It ensures systems operate smoothly and efficiently  
d) It allows for more frequent system updates
3. Which step involves coming up with a theory about what might be causing a problem?  
a) Test the Theory to Determine the Cause   b) Establish a Theory of Probable Cause  
c) Implement the Solution   d) Verify Full System Functionality
4. After implementing a solution, what is the next step in the troubleshooting process?  
a) Document Findings, Actions, and Outcomes  
b) Test the Theory to Determine the Cause  
c) Verify Full System Functionality  
d) Establish a Plan of Action to Resolve the Problem
5. Which of the following is an example of identifying a problem in troubleshooting?  
a) Testing a laptop battery by plugging in the power cord  
b) Coming up with a plan to replace a laptop battery  
c) Noticing that a laptop does not turn on when the power button is pressed  
d) Writing down that a laptop battery was replaced
6. Why is documenting findings, actions, and outcomes important in troubleshooting?



- a) It helps solve problems faster
  - b) It provides a record for future reference
  - c) It allows for more efficient testing
  - d) It ensures the solution is implemented correctly
7. What is the purpose of establishing a plan of action in troubleshooting?
- a) To identify the problem
  - b) To verify full system functionality
  - c) To determine the cause of the problem
  - d) To decide on the steps needed to resolve the issue
8. Why is troubleshooting important in computing systems?
- a) It ensures hardware components are always up to date
  - b) It prevents the need for data backups
  - c) It helps keep systems running smoothly and securely
  - d) It eliminates the need for software updates
9. What does troubleshooting help prevent by quickly identifying and resolving issues?
- a) The need for professional help
  - b) The need for software updates
  - c) Downtime and lost productivity
  - d) The need for regular maintenance
10. Which of the following is an example of ensuring data integrity through troubleshooting?
- a) Identifying a software bug that causes incorrect database results
  - b) Replacing a faulty printer
  - c) Using a cooling pad to prevent laptop overheating
  - d) Updating the operating system regularly

### Short Questions

1. What is the first step in the systematic process of troubleshooting, and why is it important?
2. After identifying a problem, what is the next step in troubleshooting, and how does it help in resolving the issue?
3. Describe the importance of testing a theory during the troubleshooting process. Provide an example.
4. Explain what the "Implement the Solution" step entails in a troubleshooting.



5. Why is it necessary to verify full system functionality after implementing a solution?

### **Long Questions**

1. Discuss the importance of troubleshooting in maintaining the smooth operation of systems, especially computing systems.
2. Explain the systematic process of troubleshooting. Describe each step in detail.
3. Using a case study where a printer is not printing, explain how you would identify the problem and establish a theory of probable cause.
4. Discuss the importance of documenting findings, actions, and outcomes during the troubleshooting process.
5. Analyze the various ways troubleshooting is vital in computing systems, particularly in preventing downtime, ensuring data integrity, and improving security. Provide specific examples and scenarios to support your analysis.
6. Describe basic software-related troubleshooting strategies, including handling application freezing and unresponsive peripherals.
7. Explain how to recognize hardware failures, particularly focusing on RAM and hard drive issues.
8. Elaborate on the importance of maintaining software and addressing security threats.
9. Describe common methods for identifying and removing malware infections and applying operating system updates for security.
10. Describe the different data backup methods, including using external storage devices and cloud solutions.



# UNIT 5

## Software System

### Student Learning Outcomes

**By the end of this chapter, you will be able to:**

1. Identify and explain the significance of system software and application software.
2. Understand the role and main functions of system software.
3. Explain how operating systems manage hardware resources, provide user interfaces, and run applications.
4. Describe how utility software enhances system performance, security, and maintenance.
5. Understand how device drivers facilitate communication between hardware devices and the operating system.
6. Recognize the main functions of commonly used application software, such as word processing, spreadsheet, presentation, and graphic design applications.
7. Discuss the uses and significance of various application software in different domains (e.g., business, education, graphics design, etc.).
8. Differentiate between system software (e.g., operating systems, utility software, device drivers) and application software in terms of their roles and functions.
9. Proficiently use prominent system software including operating systems, utility software, and device drivers.
10. Navigate the user interface, manage files, and perform system tasks using operating systems.
11. Utilize utility software and tools for optimizing system performance and maintaining security. Install, update, and troubleshoot device drivers for various hardware components
12. Use commonly used application software to perform specific tasks or create content (e.g., word processing, spreadsheets, presentations).
13. Identify appropriate software tools for specific tasks, taking into account their functions and capabilities.
14. Use application software for productivity, creativity, and communication purposes.
15. Demonstrate and differentiate between system software and application software, understanding their roles within a computer system.



## Introduction

Software is an integral part of any computing system, acting as the intermediary between the user and the hardware. In this chapter, we will explore the significance of system software and application software, understanding their roles, functions, and applications in various domains. By the end of this chapter, students will be proficient in identifying, using, and differentiating between different types of software.

### 5.1 Software

Software is a collection of programs and instructions that tell a computer what to do and how to do. Without software, computers would be useless machines.



The first computer virus, called "Creeper," was created in 1971 as an experimental self-replicating program. It simply displayed the message, "Fm the creeper, catch me if you can!"

#### 5.1.2 Types of Software

##### 5.1.2.1 System Software

System software is designed to manage the system resources and provide a platform for application software to run. It acts as a bridge between the hardware and the user applications. Here are some examples:

- **Operating Systems:** Examples include Microsoft Windows, macOS, and Linux.
- **Device Drivers:** These include printer drivers, graphics card drivers, and sound card drivers.
- **Utility Programs:** Examples are antivirus software, disk cleanup tools, and backup software.

##### 5.1.2.2 Application Software

Application software is designed to help users perform specific tasks. These programs are built to fulfill user needs and are typically more varied than system software. Examples include:

- **Word Processors:** Such as Microsoft Word and Google Docs.
- **Web Browsers:** Such as Google Chrome, Mozilla Firefox, and Safari.
- **Games:** Such as Minecraft, Fortnite, and Among Us.
- **Media Players:** Such as VLC Media Player and Windows Media Player.

##### 5.1.2.3 Differentiating Between System Software and Application Software

- **Purpose:** System software manages and operates computer hardware, making it possible for application software to run. Application software helps the user to perform specific tasks.
- **Examples:** System software includes operating systems and device drivers. Application software includes word processors, web browsers, and games.
- **Installation:** System software is usually pre-installed on a computer, while application software can be installed by the user as needed.



Always keep your system software updated to ensure your computer runs smoothly and is protected from security threats.

### Class activity

Make a list of all the software you use on your computer or tablet. Categorize them into system software and application software. Discuss with your classmates which software you find most useful and why.

## 5.2 Introduction to System Software

System software is essential for the operation of a computer system, acting as an intermediary between the hardware and the user applications. It ensures that the hardware components of a computer work together efficiently and provides a stable environment for application software to run. Here, we discuss the role and main functions of system software in detail.

### 5.2.1 Operating System

**An Operating System (OS)** is a type of system software that manages all the hardware and software on a computer. It acts as an intermediary between the computer hardware and the user applications. The operating system ensures that different programs and users running on a computer do not interfere with each other. It also provides a stable and consistent way for applications to interact with the hardware without having to know all the details of the hardware. Some most commonly used operating systems are:

**Windows:** A popular OS for personal computers developed by Microsoft. It has a start menu, taskbar, and windows for applications. See Figure 5.1.

**macOS:** An OS for Apple's Mac computers. It has a dock at the bottom of the screen and unique features like Mission Control. See Figure 5.2.

**Linux:** An open-source OS that is used for everything from servers to desktop computers. It can look different depending on the distribution (version) you use. See Figure 5.3.

**Android:** An OS for smartphones and tablets, developed by Google. It is used on many different devices from various manufacturers.

**iOS:** An OS for iPhones and iPads, developed by Apple. It is known for its smooth performance. Let's study some key functions of an operating system.



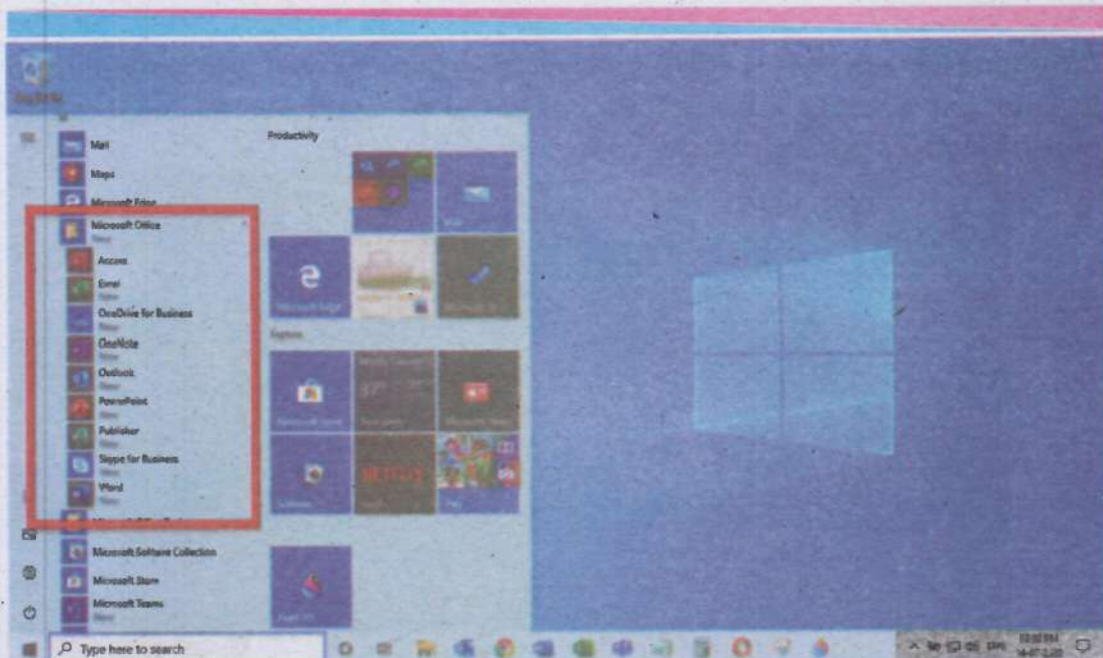


Figure 5.1: Screenshot of a Windows desktop

### 5.2.1.1 Managing Hardware Resources

One of the primary functions of an operating system is to manage the hardware resources of a computer system. This includes the CPU, memory, disk drives, and peripheral devices such as printers and keyboards. The OS ensures that each application gets the necessary resources to function correctly without interfering with other applications.

**Example:** When you open a web browser while listening to music on your computer, the operating system allocates CPU time and memory to both the web browser and the music player. It ensures that both applications run smoothly by managing the resources effectively.

### 5.2.1.2 Providing a User Interface

The operating system provides a User Interface (UI) that allows users to interact with the computer.

There are two main types of user interfaces:

- Graphical User Interfaces (GUIs)
- Command-Line Interfaces (CLIs).

**Graphical User Interface (GUI):** A GUI allows users to interact with the computer using visual elements such as windows, icons, and menus. This type of interface is user-friendly and intuitive, making it easy for users to navigate and perform tasks.

**Example:** Microsoft Windows and macOS are operating systems that use GUIs. Users can click on icons to open applications, drag and drop files to move them, and use menus to access different functions.



**Command-Line Interface (CLI):** A CLI requires users to type text commands to perform specific tasks. This interface is more flexible and powerful, but it can be more difficult for beginners to use.

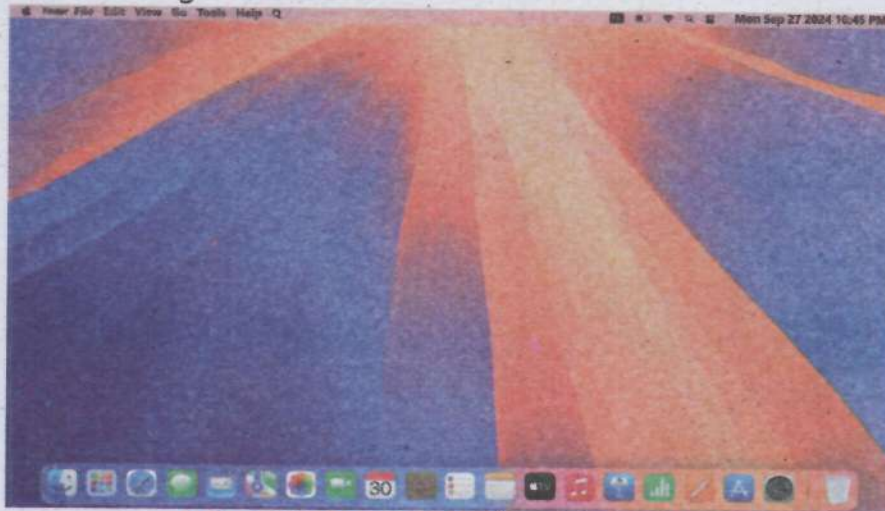


Figure 5.2: Screenshot of a macOS desktop

**Example:** Linux and Disk Operating System (DOS) provide CLIs. Use can type commands to copy files, run programs, and configure system settings.

### 5.2.1.3 Running Applications

The operating system is responsible for running applications on a computer. It loads applications into memory, allocates the necessary resources, and manages their execution. The OS also ensures that applications do not interfere with each other and that they run efficiently.

**Example:** When you open a word processor like Microsoft Word, the operating system loads the application into the computer's memory and allocates CPU time for it to run. If you open multiple applications, the OS manages the distribution of resources so that all applications can run simultaneously without performance issues.

#### Tidbits

To keep your operating system running smoothly, regularly update it to the latest version and perform routine maintenance tasks such as disk cleanup and virus scans.

#### Class activity

Explore the task manager (Windows) or activity monitor (Mac) on your computer. Identify the different running applications and observe how much CPU and memory each application is using. Discuss why the operating system's role in managing these resources is crucial for the computer's performance.



### 5.2.2 Utility Programs

Utility programs are essential components of system software that enhance the functionality of a computer system. They perform various tasks to ensure smooth operation and efficient management of hardware, software, and data. Here are some common utility programs along with their functionalities in real-life scenarios.

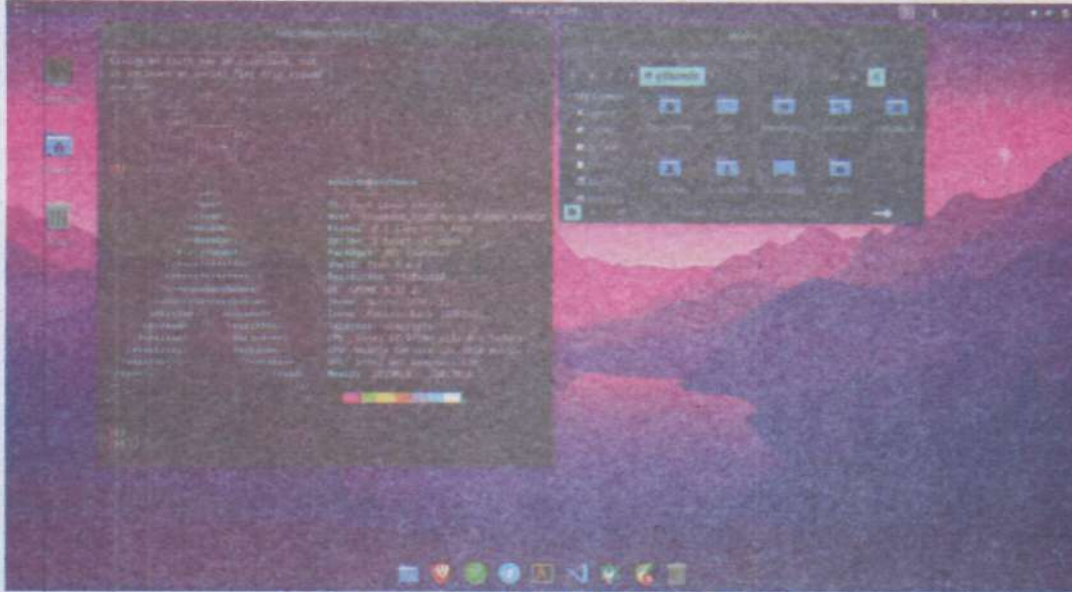


Figure 5.3: Screenshot of a Linux desktop

#### 5.2.2.1 Disk Cleanup

**Functionality:** Disk Cleanup scans your hard drive for temporary files, cached files, and other unnecessary items that can be safely deleted.

**Real-life Scenario:** After using your computer for a while, you notice it's running slower than usual. Running Disk Cleanup can help reclaim disk space, potentially improving performance.

#### 5.2.2.2 Antivirus Software

**Functionality:** Antivirus software scans files and incoming data for known viruses and malware signatures. It also provides real-time protection to prevent virus attacks.

**Real-life Scenario:** You receive an email attachment from an unknown sender. Before opening it, you run your antivirus software to scan for any potential threats, ensuring your computer remains safe.

#### 5.2.2.3 Backup Software

**Functionality:** Backup software schedules regular backups of files and folders to external drives, cloud storage, or network locations. It allows for full system backups or selective file backups.

**Real-life Scenario:** You accidentally delete an important presentation file. Using backup software, you retrieve the latest backup version of the file, ensuring minimal disruption to your work.



File compression tools reduce file size to save storage space and make file transfer faster.

**Tidbits**

### 5.2.2.4 File Compression Tools

**Functionality:** File compression tools compress one or multiple files into a single archive format (e.g., ZIP, RAR) while preserving data integrity. They also provide options for encryption and password protection.

**Real-life Scenario:** You need to send a large folder of high-resolution photos via email. Using a file compression tool, you create a ZIP archive to reduce file size, making it easier and quicker to upload and send.

These utility programs are essential for maintaining the efficiency, security, and reliability of your computer system. Understanding their functionalities can help you better manage and optimize your computing experience.

### 5.2.3 Device Drivers

Device drivers facilitate communication between hardware devices and the operating system, ensuring that devices function correctly. Imagine your computer as a superhero with many powers, but sometimes it needs help to talk to its gadgets, like a printer, keyboard, or mouse. Here's where device drivers come in. A device driver is like a translator between the computer and its gadgets.

**Printer Driver:** Helps the computer send the correct signals to the printer, so it can print documents.

- **Graphics Card Driver:** Makes sure the computer can display images and videos correctly on the screen.

How Device Drivers Work

1. **Installation:** When you connect a new device to your computer, you often need to install a driver.
2. **Communication:** The driver acts as a translator, converting general instructions from the computer into specific instructions that the device can understand.
3. **Operation:** Once installed, the driver helps the computer and the device to work together smoothly.

**Real-Life Analogy:** TV Remote Control

Think of a device driver like a TV remote control:

- **TV (Device):** It can change channels, adjust the volume, and more, but it needs instructions.
- **Remote Control (Driver):** Sends the correct signals to the TV to perform these actions.
- **You (Computer):** You decide what you want to watch or adjust and use the remote control to tell the TV.





A Plug and Play (PnP) device automatically configures itself when connected to a computer, simplifying installation and use.

When installing a new device, always check for the latest driver updates to ensure compatibility and optimal performance.

**Tidbits**



The first operating system was created in the 1950s for IBM computers and was called GM-NAA I/O.

## 5.3 Application Software

Application software refers to programs designed to perform specific tasks for users, ranging from productivity and creativity to entertainment and education. These software applications utilize the capabilities of the underlying operating system and hardware to fulfill user needs effectively. Here are some common types of application software along with their functionalities and class activities:

### 5.3.1 Commonly used application software

#### 5.3.1.1 Word Processing Software

Word processing software is a type of application software used for creating, editing, formatting, and printing documents. These software programs are essential tools for writing letters, reports, essays, and other text-based documents. Word processors offer a variety of features that enhance the writing and editing process, making it easier for users to produce professional-quality documents.

#### Examples of Word Processing Software:

- **Microsoft Word:** Available on Windows and macOS, Microsoft Word is one of the most widely used word processors. It offers a range of features including text formatting, spell check, grammar check, and the ability to insert images, tables, and charts.
- **Google Docs:** A web-based word processor available on any operating system with internet access. Google Docs allows for real-time collaboration, where multiple users can edit a document simultaneously. It also integrates with other Google services.
- **Apple Pages:** Available on macOS and iOS, Apple Pages provides a user-friendly interface with powerful tools for creating beautiful documents. It includes templates, design tools, and easy integration with other Apple products.
- **LibreOffice Writer:** Available on Windows, macOS, and Linux, LibreOffice Writer is a free and open-source word processor. It offers a robust set of features similar to Microsoft Word, making it a great alternative for users who prefer open-source software.





AI-based tools like Grammarly and Microsoft Editor are revolutionizing word processing by providing advanced grammar, style, and tone suggestions. These tools help users write more clearly and effectively by offering real-time feedback and corrections.

### 5.3.1.2 Spreadsheet Software

Spreadsheet software is a type of application software used for organizing, analyzing, and storing data in tabular form. Spreadsheets consist of a grid of cells arranged in rows and columns, where users can input data, perform calculations, and create charts. This software is essential for tasks such as budgeting, financial analysis, data management, and statistical analysis.

Examples of Spreadsheet Software:

- **Microsoft Excel:** Available on Windows and macOS, Microsoft Excel is one of the most widely used spreadsheet programs. It offers powerful features including complex formulas, pivot tables, and a variety of chart options.
- **Google Sheets:** A web-based spreadsheet available on any operating system with internet access. Google Sheets allows for real-time collaboration, where multiple users can edit a spreadsheet simultaneously. It also integrates with other Google services.
- **Apple Numbers:** Available on macOS and iOS, Apple Numbers provides a user-friendly interface with strong visualization tools for creating visually appealing spreadsheets. It includes templates and easy integration with other Apple products.
- **LibreOffice Calc:** Available on Windows, macOS, and Linux, LibreOffice Calc is a free and open-source spreadsheet program. It offers a robust set of features similar to Microsoft Excel, making it a great alternative for users who prefer open-source software.



AI-based tools in spreadsheet software, such as Microsoft's Ideas in Excel and Google Sheets' Explore feature, help users analyze data by providing insights, suggesting formulas, and creating charts automatically.

### 5.3.1.3 Graphic Design Software

Graphic design software is a type of application software used for creating, editing, and managing visual content. These programs provide tools for drawing, painting, photo editing, and creating illustrations, making them essential for designers, artists, and anyone involved in visual media. Graphic design software is used in various industries, including advertising, web design, publishing, and multimedia production.



### Examples of Graphic Design Software:

- **Adobe Photoshop:** Available on Windows and macOS, Adobe Photoshop is one of the most popular graphic design programs. It offers powerful tools for photo editing, digital painting, and graphic design.
- **Adobe Illustrator:** Available on Windows and macOS. Adobe Illustrator is a vector graphics editor used to create logos, illustrations, and scalable graphics that maintain quality at any size.
- **CorelDRAW:** Available on Windows and macOS, CorelDRAW is a vector graphics editor known for its user-friendly interface and robust feature set, ideal for creating professional graphics and layouts.
- **GNU Image Manipulation Program (GIMP):** Available on Windows, macOS, and Linux, GIMP is a free and open-source graphic design program. It offers many features similar to Adobe Photoshop, making it a great alternative for users who prefer open-source software.
- **Canva:** A web-based graphic design tool accessible on any operating system with internet access. Canva provides an easy-to-use interface with a wide range of templates and design elements, making it perfect for beginners and professionals alike.



AI-based tools in graphic design software, such as Adobe Sensei in Photoshop and Illustrator, help designers by automating repetitive tasks, suggesting design elements, and enhancing images with advanced algorithms.

### Summary

- Software systems include all the programs and applications that enable us to perform specific tasks on a computer.
- The primary objective of software as a system is to manage hardware resources and provide a platform for applications to run smoothly.
- System software manages the hardware and basic system operations, while application software helps users perform specific tasks.
- The main functions of system software include managing hardware resources, providing a user interface, and running applications.
- Utility software enhances system performance and ensures security and maintenance, and device drivers, which facilitate communication between hardware devices and the operating system.
- In business, application software streamlines operations, improves productivity, and enhances communication.
- In education, application software enhances the learning experience, improves administrative efficiency, and facilitates communication between teachers, students, and parents.



## EXERCISE

### Multiple Choice Questions (MCQs)

1. What is the primary function of an operating system?
  - (a) To create documents
  - (b) To manage hardware resources and provide a user interface
  - (c) To perform calculations
  - (d) To design graphics
2. Which software is used to enhance system performance and security?
  - (a) Operating system
  - (b) Utility software
  - (c) Application software
  - (d) Device drivers
3. What role do device drivers play in a computer system?
  - (a) Manage files
  - (b) Facilitate communication between hardware devices and the operating system
  - (c) Create presentations
  - (d) Enhance graphics performance
4. Which of the following is an example of application software?
  - (a) Microsoft Word
  - (b) BIOS
  - (c) Disk Cleanup
  - (d) Device Manager
5. What is the main purpose of a spreadsheet software?
  - (a) To edit text documents
  - (b) To organize and analyze data
  - (c) To create visual content
  - (d) To enhance system security
6. How does utility software differ from application software?
  - (a) Utility software manages hardware, while application software performs specific tasks for users.
  - (b) Utility software creates documents, while application software manages hardware.
  - (c) Utility software performs specific tasks for users, while application software manages hardware.
  - (d) Utility software is free, while application software is paid.
7. Which type of software would you use to design a logo?
  - (a) Operating system
  - (b) Spreadsheet software
  - (c) Graphic design software
  - (d) Utility software
8. What is the function of system software?
  - (a) To facilitate communication between hardware and software
  - (b) To perform specific tasks for the user
  - (c) To create visual content
  - (d) To organize and analyze data
9. Why are operating system updates important?
  - (a) They increase screen brightness
  - (b) They add more fonts
  - (c) They enhance security and fix bugs
  - (d) They improve battery life



10. What is a common task you can perform using word processing software?

- (a) Create and edit text documents
- (b) Manage hardware resources
- (c) Enhance system performance
- (d) Organize and analyze data

### Short Questions

1. Define system software and provide two examples.
2. Explain the primary functions of an operating system.
3. What is utility software and why is it important?
4. Describe the role of device drivers in a computer system.
5. Differentiate between system software and application software with examples.
6. What are the main functions of spreadsheet software?
7. How can graphic design software be used in the field of education?
8. What is the significance of data backups and how can they be performed?

### Long Questions

1. Discuss the importance of system software in a computing system.
2. Describe the roles of operating systems, utility software, and device drivers, providing examples of each.
3. Explain the differences between system software and application software.
4. Describe the process of using utility software to optimize system performance and maintain security. Provide detailed steps and examples of common utility tools.
5. Explain how to install, update, and troubleshoot device drivers for hardware components.
6. Discuss the main functions of commonly used application software, such as word processing, spreadsheet, presentation, and graphic design applications.



# UNIT 6

## Introduction to Computer Networks

### Student Learning Outcomes

By the end of this chapter, you will be able to:

- Understand and explain computer networks as systems, their objectives, components, and data communication among these components.
- Understand fundamental concepts in data communication, including sender, receiver, protocol, message, and communication medium.
- Understand key concepts related to computer networks, including networking devices, network topologies, and transmission modes.
- Understand the 7-layer OSI networking model and its related protocols.
- Understand the benefits of using computer networks, such as resource sharing and data communication.
- Understand how data is transmitted across computer networks, including packet and circuit switching, and secure communication through encapsulation.
- Understand how protocols, data, packets, and network services like DNS and DHCP function in a networked environment.
- Understand different methods of network security, their advantages, and disadvantages.
- Understand real-world applications of computer networks, including various network-based services and how they are used.
- Know standard protocols involved in TCP/IP communications.
- Know key networking terms like the 5-layer OSI networking model, packet switching, circuit switching, router, TCP/IP, IP, UDP, DNS, DHCP, host, browsers, layering, encapsulation, and various protocols involved in TCP/IP communications.
- Differentiate between components of data communication.
- Differentiate networking devices and network topologies.
- Differentiate transmission modes.
- Identify and describe different types of networks using the 7-layer OSI networking model.
- Explain how data is transmitted across networks and describe the standard protocols involved.
- Define and explain the uses of protocols, data, packets, and network services like DNS and DHCP.
- Describe different methods of network security and their advantages and disadvantages.



## Introduction

In today's interconnected world, computer networks play a vital role in the functioning of societies and businesses. This chapter aims to provide a comprehensive understanding of computer networks as systems, including their components, objectives, and real-world applications.

### 6.1 Network as a System

A computer network is a system of linked devices and computers that may exchange data and operate together. Networks can range from small, Local Area Network (LANs, Local Area Networks) to large area network, WANs, including the Internet. Networks are arranged of various elements that work together to facilitate communication depicted in Figure 6.1.

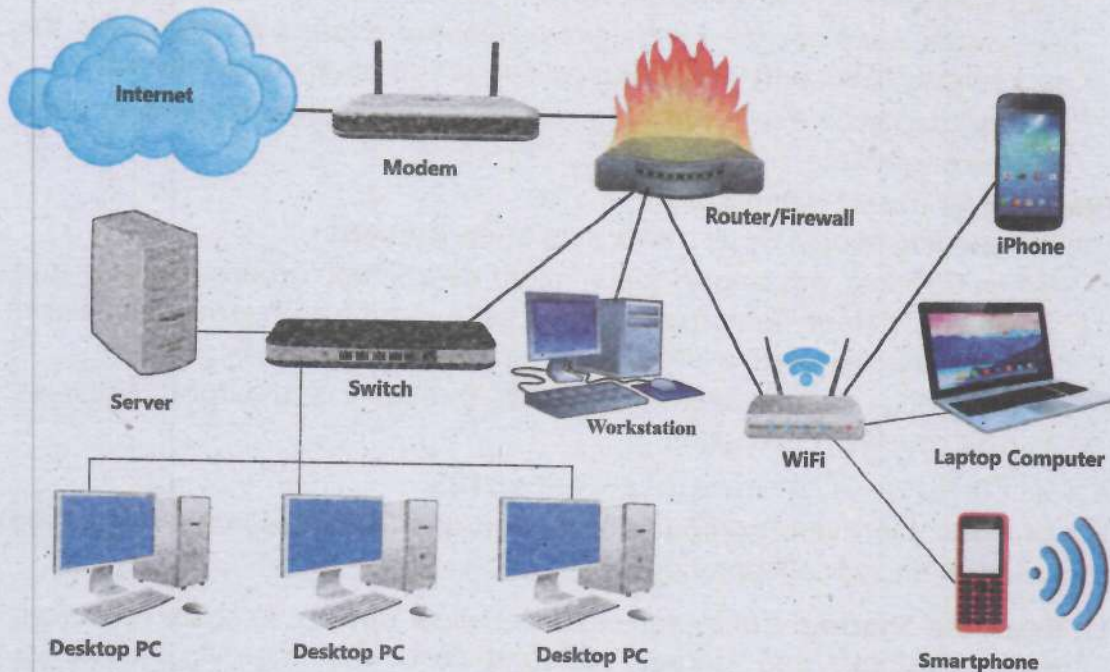


Figure 6.1: Network Diagram

The primary components include:

- **Nodes:** Devices that are connected to the network, such as computers, smartphones, and printers.
- **Links:** The connections between nodes, which can be wired (like Ethernet cables) or wireless (like Wi-Fi).
- **Switches:** Devices that connect multiple nodes within a network to forward data.
- **Routers:** Devices that connect different networks and direct data packets between them.





The Internet is the largest network, connecting all the networks worldwide!

- **Example of Using Switches**

- Imagine a file transfer in an office network. You send a file from your computer to a colleague's computer in another room.
- The file is split into packets, and each packet has the destination MAC address (your colleague's computer).
- The packets are sent to a network switch.
- The switch examines the Media Access Control address and forwards the packets only to the port where your colleague's computer is connected.
- Once all packets are received, your colleague's computer reassembles them into the original file.

**Example:** Air Travel System

Think of sending people via air travel. Here's how it relates:

- When traveling, passengers (data) might be split into groups (packets) and assigned different flights (paths). In packet switching each group has a ticket with the final destination (IP address).
- These groups might take different routes, through various airports (routers), to reach the final destination.

### 6.1.1 Objectives of Computer Networks

The primary objective of computer network is to enable resource sharing, data communication and collaboration:

1. **Resource Sharing:** Computer networks allow devices to share resources, such as printers and storage, reducing costs and improving efficiency.  
**Example:** In an office network, multiple computers can share a single printer, reducing the need for multiple printers.
2. **Data Communication:** Networks facilitate data transfer, enabling communication through emails, instant messaging, and video conferencing.  
**Example:** Employees in different locations can collaborate through video conferencing tools like Zoom or Microsoft Teams.
3. **Connectivity and Collaboration:** Networks connect devices, allowing for remote access and collaboration, improving productivity and flexibility.  
**Example:** A team can work on a shared document in real-time using cloud-based services like Google Drive.





The World Wide Web (WWW) was invented by Tim Berners-Lee in 1989, revolutionizing how we access and share information.

## 6.2 Fundamental Concepts in Data Communication

Data communication involves the exchange of data between a sender and a receiver through a communication medium. Key components include the sender, receiver, message, protocol, and medium.

### 6.2.1 Components of Data Communication

It comprises of five basic components:

1. **Sender:** The device that sends the data. **Example:** A computer sending an email.
2. **Receiver:** The device that receives the data. **Example:** A smartphone receiving the email.
3. **Message:** The data being communicated. **Example:** The content of the email.
4. **Protocol:** A set of rules governing data communication. **Example:** The HTTP protocol used for web communications.
5. **Medium:** The physical or wireless path through which data travels. **Example:** Ethernet cable or Wi-Fi.

## 6.3 Networking Devices

Networking devices include hubs, switches, routers, and access points are responsible for the management and direction of network traffic.

### 6.3.1 Switch

Switch is a network device that connects multiple network devices such as computers, printers, and servers, within a network and allows these devices to communicate with each other efficiently. Switches play an important role in modern networks by efficiently managing data traffic and ensuring that information reaches the correct device.

#### How Does a Switch Work?

A switch is used at the Data Link layer which is called the Layer 2 of the OSI model (Section 6.6). It uses hardware address of a device called Media Access Control (MAC) addresses to forward data to the correct device. When a data packet reaches at the switch, it reads the destination MAC address and sends the packet only to the device with that address, rather than broadcasting it to all devices.



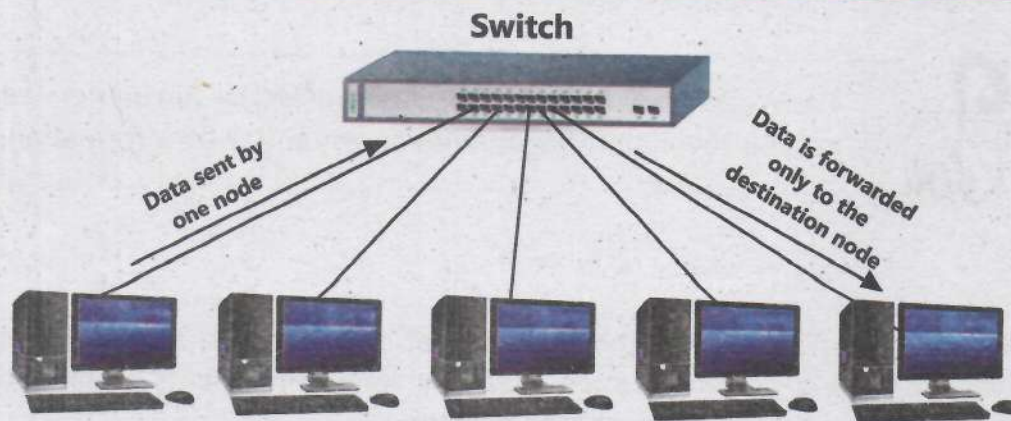


Figure 6.3: A network switch connecting multiple devices.

### Tidbits

First time, switch forwards or broadcast data to all connected devices. Once it has learned address of devices, it starts sending data to exact destination.



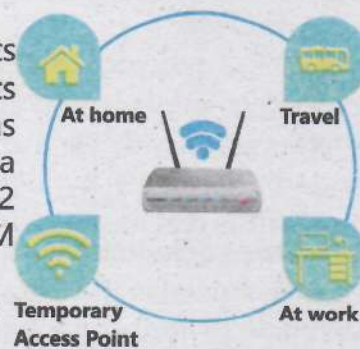
A switch is like a smart traffic conductor that directs data traffic only to the intended destination, making the network faster and more efficient.

Did you know that your home router often includes a switch and a wireless access point? This allows you to connect multiple devices both wired and wirelessly!

### Tidbits

#### 6.3.2 Router

A router is a networking device that interconnects networks or allows devices to connect to it. It directs data packets between different networks. Think of it as a traffic director on the internet, making sure that data gets from one place to another efficiently. Figure 6.2 illustrates how a mobile internet connection (via SIM card) integrates with a home network. Alternatively, an Ethernet cable can be used to obtain internet access and distribute it among home devices. In enterprise environments, different types of routers are employed, as depicted in Figure 6.2.



#### Mobile Wi-Fi Router

Figure 6.2: A typical home router





SIM stands for Subscriber Identity Module.

A SIM card is a small card inserted into a mobile device that contains unique information to identify and authenticate the subscriber on a mobile network. It allows the device to connect to the network, make calls, send messages, and access Internet.

### How Does a Router Work?

**Packets:** Each packet contains part of the data and the address of the destination. The main job of router is to find the best path for each data packet to deliver its destination.



Routers use something called a routing table to decide the best path for data packets. This table lists the possible paths and helps the router make efficient decisions!

### Class activity

**Human Network Activity:** Create a simple network using the students in the class. Assign roles like computer, router, and data packet. Use strings to represent Ethernet cables and have students pass a ball (representing data) along the strings to simulate how a router directs data.

To keep your network running smoothly, always use high-quality Ethernet cables and ensure your switch is placed in a cool, ventilated area to prevent overheating.

**Tidbits**

### 6.3.3 Access Point

An **Access Point (AP)** is a networking device that facilitates the connection of wireless devices to a wired network. It works as a link between your computers and smartphones or any other wireless device and the internet.

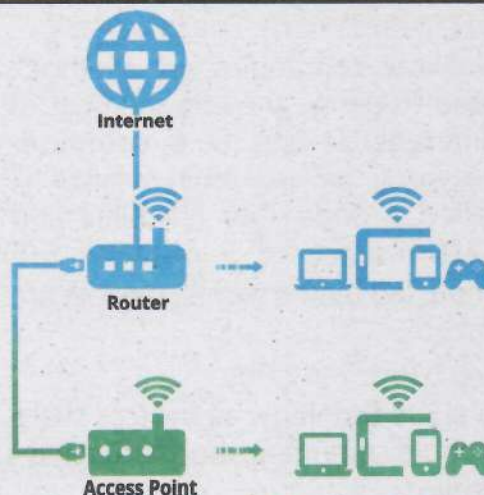


Figure 6.4: A typical Access Point



## How Does an Access Point Work?

An Access Point works by receiving data from the wired network and transmitting it wirelessly to your devices. It also receives data from your wireless devices and sends it to the wired network.

**Did You Know**

Access Points use radio waves to transmit data, similar to how your favorite radio station broadcasts music!

### Class activity

Create a human network with students. Assign roles such as Access Point, Router, and Devices. Use ropes to represent connections. Show how data moves from the Access Point to the Router and then to another network.

**Did You Know**

Did you know that modern Access Points can connect hundreds of devices simultaneously, making them perfect for schools, offices, and even stadiums?

### Tidbits

When setting up an Access Point, place it in a central location to ensure the best coverage and signal strength for all your devices!

## 6.4 Network Topologies

Network topologies are methods used to define the arrangement of different devices in a computer network, where each device is called a node. The reliability and performance of a network are impacted by the way its devices are linked.

### 6.4.1 Bus Topology

In a Bus topology, all devices share a single communication line called a bus. Each device is connected to this central cable.

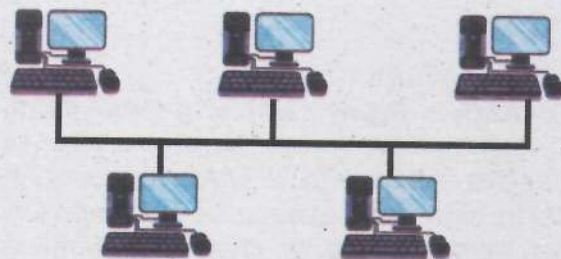


Figure 6.5: Bus Topology



### 6.4.3 Ring Topology

In a Ring topology, each device is connected in a circular pathway with other devices. Data travels in one direction, passing through each device.

**Example:** Consider a relay race where each runner passes the baton to the next runner in a circle until it reaches the starting point again.

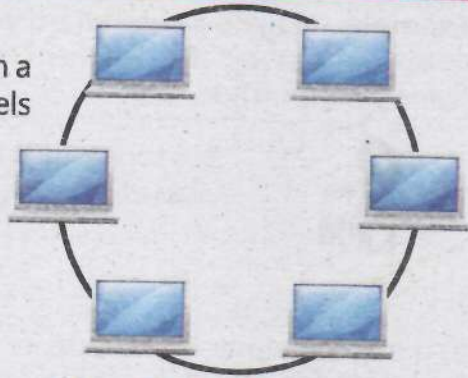


Figure 6.7 Ring Topology

Ring topology can handle high traffic, but if one connection fails, the whole network is affected. Then 2-way ring can solve this issue to some extent.

**Tidbits**

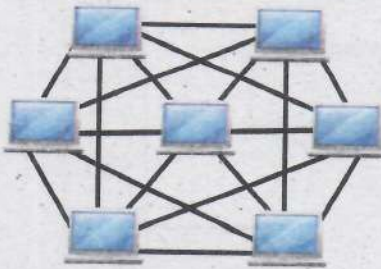


Figure 6.8: Mesh Topology

### 6.4.4 Mesh Topology

In a Mesh topology, each device is connected to every other device. This provides high redundancy and reliability.

**Example:** Imagine a city where every house is directly connected to every other house by roads. If one road is blocked, there are multiple alternative routes.



Mesh topology is very reliable because if one link fails, data can be rerouted through other links.

### Class activity

Draw your own network diagram using one of the topologies and explain how data travels from one device to another.



## 6.5 Transmission Modes

Network communication modes describe how data is transmitted between devices. There are three primary modes: Simplex, Half-Duplex, and Full-Duplex as shown in Figure 6.13. Let's explore each mode with examples and real-life analogies!

### 6.5.1 Simplex Communication

In Simplex communication, data transmission is unidirectional, meaning it flows in only one direction. A device can either send or receive data in this communication.

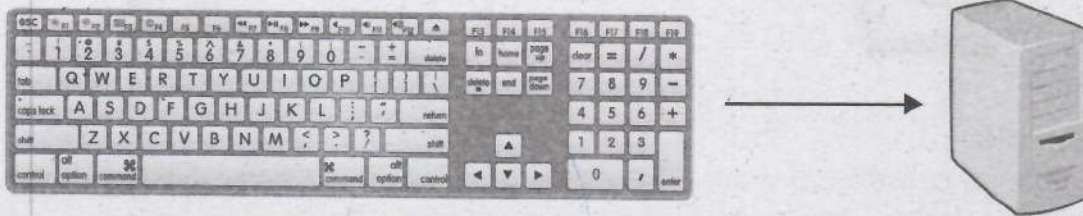


Figure 6.9: Simplex Communication

**Example:** Keyboard to computer is an example of simplex communication.



In Simplex communication, the direction of data flow is fixed, making it useful for applications where only one-way communication is needed!

### 6.5.2 Half-Duplex Communication

In Half-Duplex communication, data transmission can occur in both directions, but not simultaneously. One device must wait for the other to finish transmitting before it can start.



Figure 6.10: Half-Duplex Communication



### Class activity

Use walkie-talkies or toy telephones to demonstrate Half-Duplex communication. Let students take turns speaking and listening.

### 6.5.3 Full-Duplex Communication

Full-duplex communication allows for simultaneous data delivery in both directions. Both devices may transmit and receive data simultaneously at the same time.



Figure 6.11: Full-Duplex Communication

#### Example:

Telephone conversations are an example of Full-Duplex communication. Both people can talk and listen at the same time without waiting for their turn.

Full-Duplex communication allows for more efficient data transmission, making it ideal for modern communication systems like internet browsing and video calls !

**Tidbits**

**Did You Know**

The first telephones were Half-Duplex, where only one person could speak at a time. Modern phones use Full-Duplex, allowing both people to talk and listen simultaneously!

### Class activity

Draw a diagram of each communication mode and label the direction of data flow. Explain your diagrams to the class.

**Did You Know**

The first message sent over the ARPANET, the precursor to the internet, was "LO." It was meant to be "LOGIN," but the system crashed after the first two letters.



## 6.6 The OSI Networking Model

The Open Systems Interconnection (OSI) Model is a framework used to understand how different networking protocols interact. It has 7 layers, each with a specific function. Let's explore these layers with examples and relate them to daily life.

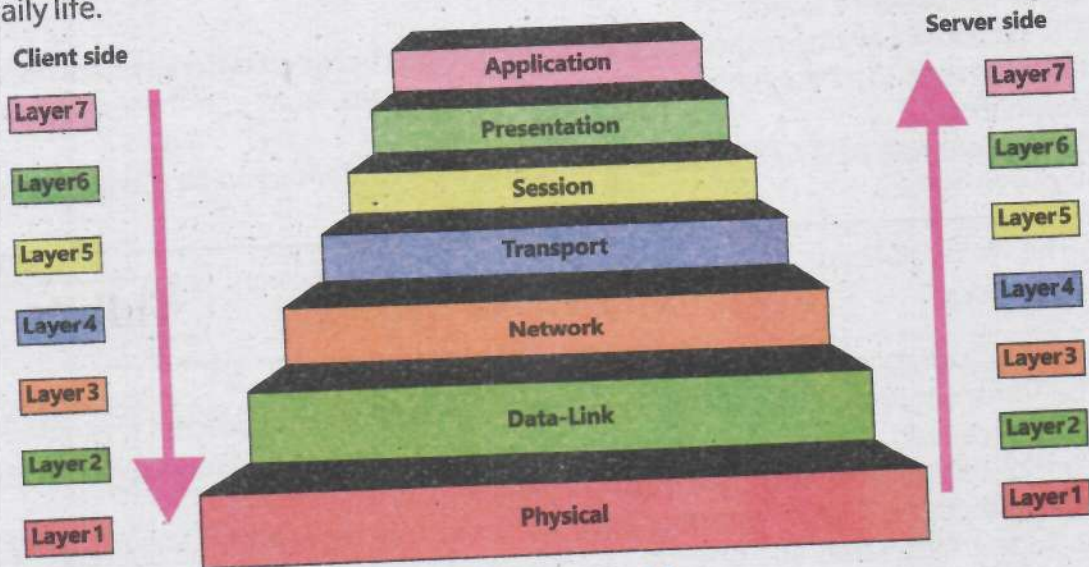


Figure 6.12: OSI Model

### Layer 1: Physical Layer

The Physical Layer is liable for the actual connection between devices. The process of sending unprocessed data bits via a physical medium is the focus here.

**Example:** Imagine the hardware that connects computers, like a Network interface cables, repeaters, hubs and connectors.



The Physical Layer includes everything from the cables to the voltage levels used to transmit data!

### Layer 2: Data Link Layer

Error detection and correction, as well as node-to-node data transport, are handled by the Data Link Layer. It ensures error-free data transmission from the Physical Layer.

**Example:** Think of the Data Link Layer as traffic lights at intersections, which manage the flow of cars (data) and prevent collisions.



### Class activity

Draw a simple network with devices and label the physical connections and data link layer responsibilities.

### Layer 3: Network Layer

The Network Layer is responsible for data transfer between different networks. It determines the best path for data to travel from the source to the destination.

**Example:** Imagine a GPS system finding the best route for you to travel from home to school.

The Network Layer uses IP addresses to route data between networks!

**Tidbits**

### Layer 4: Transport Layer

The Transport Layer ensures that data is transferred from one process running on source end system to a process sourcing on destination end system. It manages data flow control and error checking.

**Example:** Think of the Transport Layer as a delivery service that ensures your package arrives safely and on time.

**Did You Know**

The Transport Layer uses protocols like Transmission Control Protocol (TCP) to ensure reliable data transfer!

### Layer 5: Session Layer

The Session Layer manages sessions between applications. It establishes, maintains, and terminates connections between devices.

**Example:** Imagine a phone call where the session layer sets up the call, keeps it connected, and ends it when you hang up.

### Class activity

Role-play a phone call and discuss how the session is established, maintained, and terminated.

### Layer 6: Presentation Layer

The Presentation Layer translates data between the application layer and the network. It formats and encrypts data to ensure it is readable by the receiving system.



**Example:** Think of the Presentation Layer as a translator converting a book from one language to another so that more people can read it.



The Presentation Layer handles data encryption and compression!

### Layer 7: Application Layer

The Application Layer is the closest to the end user. It provides network services directly to applications, such as email, web browsing, and file transfer.

**Example:** Imagine the Application Layer as a waiter taking your order in a restaurant and bringing your food.

#### Class activity

List the applications you use daily and identify which rely on the Application Layer for network services.

## 6.7 Ipv4 and Ipv6

Internet Protocol (IP) addresses are unique identifiers assigned to devices connected to the Internet. There are two primary versions: IPv4 and IPv6. Let's explore the differences between them with examples and relate them to daily life.

### 6.7.1 Internet Protocol version 4 (IPv4)

IPv4 is the fourth version of the Internet Protocol and the most widely used today. It uses a 32-bit address scheme, allowing for approximately 4.3 billion unique addresses. To find the total number of unique IPv4 addresses, we calculate  $2^{32}$ , which represents all possible combinations of 32 bits, i.e.,  $2^{32} = 4,294,967,296$ .

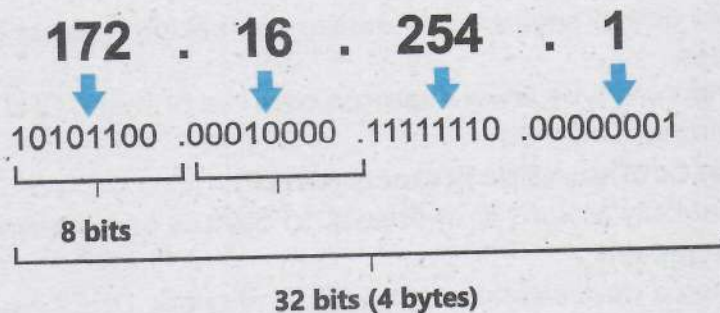
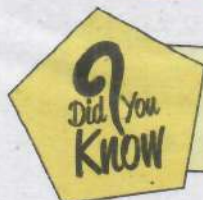


Figure 6.13: IPv4 Address Format





IPv4 addresses are written in four sets of decimal numbers, each ranging from 0 to 255 (e.g., 192.168.1.1).

### 6.7.1 Internet Protocol version 6 (IPv6)

IPv6 is the most recent version of the Internet Protocol designed to replace IPv4. It uses a 128-bit address scheme, allowing for an almost limitless number of unique addresses.

**Example:** Imagine an IPv6 address like a digital fingerprint. It can provide a unique identifier not just for houses on a street, but for every grain of sand on a beach: e.g 2001:0000:130F:0000:0900:876A:130B



IPv6 was developed to address the depletion of IPv4 addresses due to the rapid growth of the internet and connected devices.

## 6.8 Protocols and Network Services

### 6.8.1 Introduction to Protocols

Protocols are sets of rules that govern data communication. Common protocols include TCP/IP, HTTP, FTP and SMTP.

**Example:** HyperText Transfer Protocol (HTTP) is used for transferring web pages over the internet.

### 6.8.2 DNS and DHCP

#### Domain Name System (DNS)

DNS translates domain names to IP addresses, making it easier for users to access websites.

**Example:** When you type **www.example.com** in a browser, DNS translates it to the corresponding IP address.

#### Dynamic Host Configuration Protocol (DHCP)

DHCP automatically assigns IP addresses to devices on a network, simplifying network management.

**Example:** When a device connects to a Wi-Fi network, DHCP assigns it an IP address.

## 6.9 Network Security

Network security involves measures to protect data and prevent unauthorized



access to computer networks. Let's explore the importance of network security and some key concepts with examples.

### 6.9.1 Importance of Network Security

Network security is important for several reasons:

- **Data Protection:** Ensuring that sensitive information is not accessed or altered by unauthorized users.
- **Preventing Attacks:** Defending against malicious attacks that can disrupt networks and steal data.
- **Maintaining Privacy:** Safeguarding personal and confidential information from being compromised
- **Ensuring Availability:** Ensuring that network resources are available and accessible to authorized users.

### 6.9.2 Key Concepts in Network Security

#### Firewalls

Firewalls are security systems that monitor and control incoming and outgoing network traffic based on predetermined security rules.



Figure 6.14: Firewall Concept



Firewalls act as barriers between trusted internal networks and untrusted external networks, like a security checkpoint.



## Encryption

Encryption transforms data into a secure format that can only be read or understood by authorized parties with the correct decryption key. Decryption is the process of converting the encrypted data back to its original form.

### Example:

Plain Text: Hello, World!

Encrypted Text (using a simple shift cipher): Khood, Zruog! where each letter in the plaintext is replaced by the letter that is 3 positions down the alphabet.

Decryption: Converting "Khood, Zruog!" back to "Hello, World!" using the same shift cipher in reverse.

## Ciphertext Exchanged Between Countries

Countries often exchange sensitive information securely using encryption. The encrypted data, known as ciphertext, can only be read by the intended recipient who has the decryption key. This ensures national security and protects classified information from being intercepted and read by unauthorized parties.

### Class activity

Encrypt a simple message using a shift cipher with a key of 3 (each letter is shifted by 3 places in the alphabet). Then, exchange messages with a classmate and decrypt each other's messages.



During World War II, the Allies used the Enigma machine to encrypt their communications. The ability to decrypt German Enigma-encrypted messages significantly contributed to their victory.

Use strong encryption algorithms to protect sensitive information, making it unreadable to unauthorized users.

### Tidbits

## Passwords and Authentication

Passwords and authentication methods ensure that only authorized users can access network resources.

### Class activity

Discuss the importance of strong passwords and practice creating secure passwords using a password generator.

## 6.9.3 Common Threats to Network Security

- **Malware:** Malicious software such as viruses, worms, and ransomware that can damage or steal data.
- **Phishing:** Attempts to trick users into revealing sensitive information



through deceptive emails or websites.

- **Denial of Service (DoS) Attacks:** Overwhelming a network with traffic to disrupt its normal operation and make it unavailable.
- **Man-in-the-Middle Attacks:** Intercepting communication between two parties to steal information or alter messages.

## 6.10 Types of Networks

Networks are classified based on their size, range, and purpose. Let's explore some common types of networks and understand how they work.

### 6.10.1 Personal Area Network (PAN)

A PAN is a small network used for communication between personal devices, such as smartphones, tablets, and laptops, within a short range. **Example:** Bluetooth connections between a smartphone and a wireless headset form a PAN.



Figure 6.15: Personal Area Network (PAN)



The range of a PAN is typically a few meters, perfect for personal device communication.

### Local Area Network (LAN)

A LAN is a network that connects computers and devices within a limited area, such as a home, school, or office building.

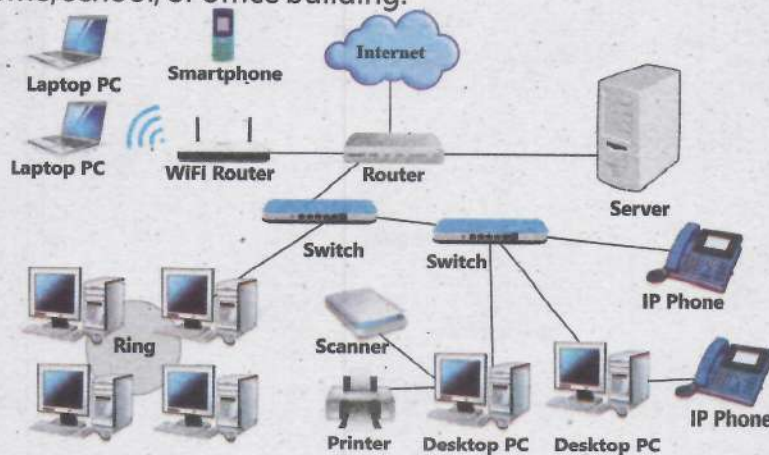


Figure 6.16: Local Area Network (LAN)



**Example:** The computer network in your school that connects all the computers in the lab is a LAN.

**Class activity**  
Draw a diagram of your school's computer network, labeling the different devices and connections.

### 6.10.1 Metropolitan Area Network (MAN)

A MAN is a network that spans a city or a large campus, connecting multiple LANs together.

**Example:** The network that connects various branches of a university across a city is a MAN.

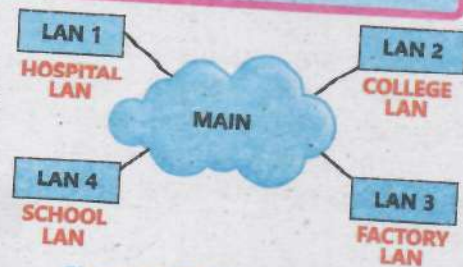


Figure 6.17: Metropolitan Area Network (MAN)

**Did You Know?**

A MAN can cover an area of up to 50 kilometers, making it ideal for city-wide connectivity.

### 6.10.1 Wide Area Network (WAN)

A WAN covers a large geographical area, connecting multiple LANs and MANs. The internet is the largest example of a WAN.

**Example:** The network that connects different branch offices of a multinational company across countries is a WAN.

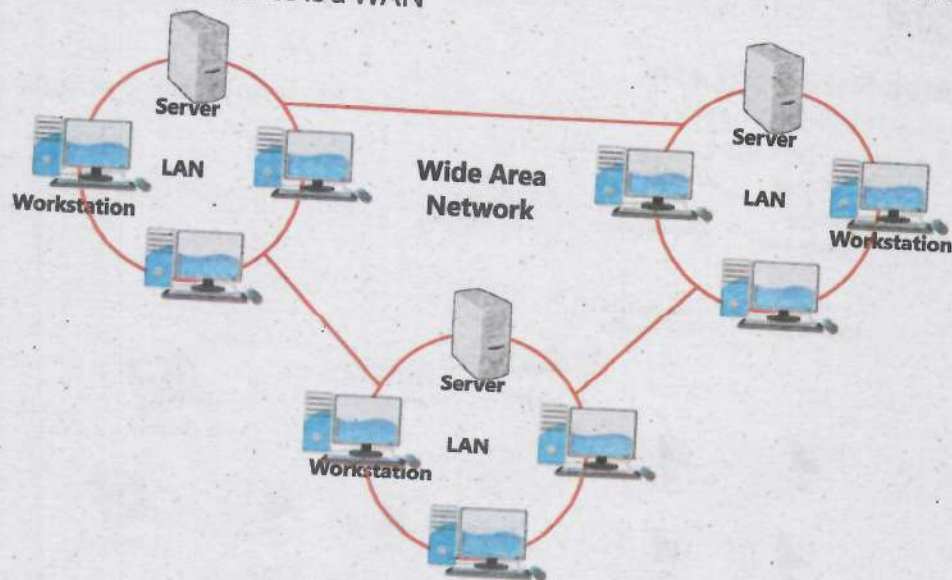


Figure 6.18: Wide Area Network (WAN)



Use a Virtual Private Network (VPN) to securely connect to a WAN and protect your data when accessing public networks.

## Tidbits

### 6.10.1 Campus Area Network (CAN)

A CAN is a network that connects multiple LANs within a limited geographical area, such as a university campus or a business park.

**Example:** The network that connects various departments and buildings within a university is a CAN.

Understanding the different types of networks helps us comprehend how data travels from one device to another, whether within a single room or across the globe. Each network type serves a specific purpose and is designed to handle various ranges and sizes.

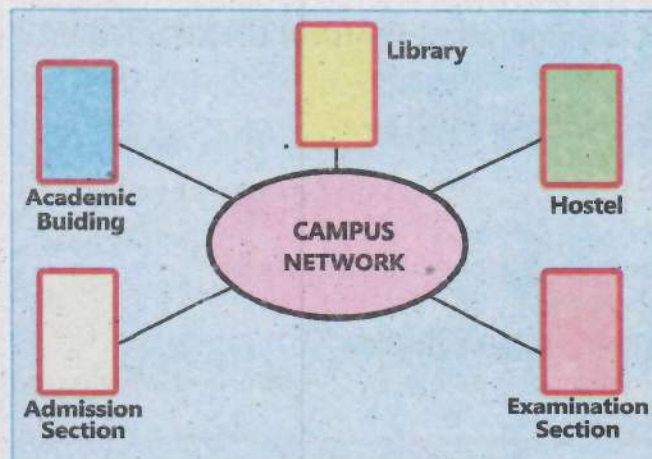


Figure 6.19: Campus Area Network (CAN)

## 6.11 Real-World Applications of Computer Networks

### 6.11.1 Business

In business, networks enable efficient communication, resource sharing, and data management.

**Example:** Companies use intranets to share information and resources securely within the organization.

### 6.11.1 Education

Educational institutions use networks to provide online learning platforms, virtual classrooms, and access to educational resources.

**Example:** Universities use Learning Management Systems (LMS) like Blackboard and Moodle to deliver course content and assessments.

### 6.11.2 Healthcare

Healthcare networks facilitate the sharing of patient information, telemedicine,



and access to medical databases.

**Example:** Hospitals use Electronic Health Records (EHR) systems to store and retrieve patient data efficiently.

## 6.12 Standard Protocols in TCP/IP Communications

### 6.12.1 Introduction to TCP/IP

TCP/IP (Transmission Control Protocol/Internet Protocol) is the fundamental suite of protocols for internet communication.

### 6.12.2 Key Protocols

- **Transmission Control Protocol (TCP):** Ensures reliable data transfer.
- **Internet Protocol (IP):** Handles addressing and routing of data packets.
- **User Datagram Protocol (UDP):** Provides faster, but less reliable, data transfer.
- **Domain Name System (DNS):** Translates domain names to IP addresses.
- **Dynamic Host Configuration Protocol (DHCP):** Automatically assigns IP addresses.

## 6.13 Network Security Methods

### 6.13.1 Firewalls

Monitor and control incoming and outgoing network traffic.

### 6.13.2 Encryption

Protects data by converting it into a secure format.

### 6.13.3 Antivirus Software

Detects and removes malicious software.

**Example:** A combination of firewalls, encryption, and antivirus software provides robust network security.

#### Class activity

Have students discuss the advantages and disadvantages of different network security methods.

## Summary

- A computer network is a system of interconnected computers and devices that communicate and share resources.
- The primary objectives of computer networks are to enable resource sharing, data communication, and connectivity between devices.
- Data communication involves the exchange of data between a sender and a receiver through a communication medium.
- Protocols are sets of rules that govern data communication. Common protocols include TCP/IP, HTTP, FTP and SMTP.
- A router is a device that connects different networks together and directs data packets between them.
- When you send data over the internet, it gets broken down into smaller pieces called packets.



- A switch is a network device that connects multiple devices (like computers, printers, and servers) within a Local Area Network (LAN).
- An Access Point (AP) is a network device that allows wireless devices to connect to a wired network.
- Network topologies refer to the arrangement of different elements (links, nodes, etc.) in a computer network.
- In a Bus topology, all devices share a single communication line called a bus. Each device is connected to this central cable.
- In a Star topology, all devices are connected to a central hub or switch. The hub acts as a repeater for data flow.
- In a Ring topology, each device is connected to two other devices, forming a circular data path. Data travels in one direction, passing through each device.
- In a Mesh topology, each device is connected to every other device. This provides high redundancy and reliability.
- In Simplex communication, data transmission is unidirectional, meaning it flows in only one direction.
- In Half-Duplex communication, data transmission can occur in both directions, but not simultaneously.
- In Full-Duplex communication, data transmission can occur in both directions simultaneously.
- The Open Systems Interconnection (OSI) Model is a framework used to understand how different networking protocols interact.
- Internet Protocol (IP) addresses are unique identifiers assigned to devices connected to the Internet. There are two primary versions: IPv4 and IPv6.
- DNS translates domain names to IP addresses, making it easier for users to access websites.
- DHCP automatically assigns IP addresses to devices on a network, simplifying network management.
- Network security involves measures to protect data and prevent unauthorized access to computer networks.
- Encryption transforms data into a secure format that can only be read or understood by authorized parties with the correct decryption key.
- A PAN is a small network used for communication between personal devices, such as smartphones, tablets, and laptops, within a short range.
- A LAN is a network that connects computers and devices within a limited area, such as a home, school, or office building.
- A MAN is a network that spans a city or a large campus, connecting multiple LANs together.
- A WAN covers a large geographical area, connecting multiple LANs and MANs. The internet is the largest example of a WAN.
- A CAN is a network that connects multiple LANs within a limited geographical area, such as a university campus or a business.



## EXERCISE

### Multiple Choice Questions (MCQs)

1. What is the primary objective of computer networks?
  - (a) Increase computational power
  - (b) Enable resource sharing and data communication
  - (c) Enhance graphic capabilities
  - (d) Improve software development
2. Which device is used to connect multiple networks and direct data packets between them?
  - (a) Switch
  - (b) Hub
  - (c) Router
  - (d) Modem
3. Which layer of the OSI model is responsible for node-to-node data transfer and error detection?
  - (a) Physical Layer
  - (b) Data Link Layer
  - (c) Network Layer
  - (d) Transport Layer
4. What is the function of the Domain Name System (DNS)?
  - (a) Assign IP addresses dynamically
  - (b) Translate domain names to IP addresses
  - (c) Secure data communication
  - (d) Monitor network traffic
5. Which method of data transmission uses a dedicated communication path?
  - (a) Packet Switching
  - (b) Circuit Switching
  - (c) Full-Duplex
  - (d) Half-Duplex
6. What is encapsulation in the context of network communication?
  - (a) Converting data into a secure format
  - (b) Wrapping data with protocol information
  - (c) Monitoring network traffic
  - (d) Translating domain names to IP addresses
7. Which protocol is used for reliable data transfer in the TCP/IP model?
  - (a) HTTP
  - (b) FTP
  - (c) TCP
  - (d) UDP
8. What is the main purpose of a firewall in network security?
  - (a) Convert data into a secure format
  - (b) Monitor and control network traffic
  - (c) Assign IP addresses
  - (d) Translate domain names
9. Which network topology connects all devices to a central hub?
  - (a) Ring
  - (b) Mesh
  - (c) Bus
  - (d) Star
10. What is a key benefit of using computer networks in businesses?
  - (a) Increase computational power



- (b) Enable resource sharing and efficient communication
- (c) Enhance graphic capabilities
- (d) Improve software development

### Short Questions

1. Define data communication and list its key components.
2. Explain the role of routers in a computer network.
3. What are the main functions of the Network Layer in the OSI model?
4. Describe the difference between packet switching and circuit switching.
5. What is the purpose of the Dynamic Host Configuration Protocol (DHCP)?
6. How does encapsulation ensure secure communication in a network?
7. Differentiate between TCP and UDP in terms of data transfer reliability.
8. Explain the importance of encryption in network security.
9. What are the advantages of using a star topology in a network?
10. How do firewalls contribute to network security?

### Long Questions

1. Discuss the objectives of computer networks and provide examples of how they facilitate resource sharing and data communication.
2. In a Simplex communication system, assume data is transmitted at a rate of 500 bits per second (bps). Compute the time to transmit a message if:
  - (a) it is of 10 kilobits.
  - (b) it is of 10 kilobytes.
3. Describe how data is transmitted across computer networks using packet switching and circuit switching.
4. Discuss the role and importance of protocols in data communication. Explain the functions of key protocols such as TCP/IP, HTTP, DNS, and DHCP.
5. Evaluate different methods of network security, including firewalls, encryption, and antivirus software.
6. Describe real-world applications of computer networks in business, education, and healthcare.
7. Compare and contrast the different types of network topologies (star, ring, bus, and mesh).
8. Consider a shift cipher with a shift amount of 4.
  - (a) Encrypt the message "SECURITY".
  - (b) Decrypt the message "WMXYVMI".
9. An IPv4 address is a 32-bit number. Calculate the total number of unique IPv4 addresses possible.
  - (a) Show the calculation for the total number of IPv4 addresses.
  - (b) How many addresses are left if 10% of the total addresses are reserved for special purposes?



# UNIT 7

## Computational Thinking

### Student Learning Outcomes

By the end of this chapter, you will be able to:

- Define computational thinking and its key components: decomposition, pattern recognition, abstraction, and algorithms.
- Explain the principles of computational thinking, including problem understanding, problem simplification, and solution selection and design.
- Describe algorithm design methods, specifically flowcharts and pseudocode, and understand the differences between them.
- Create and interpret flowcharts to represent algorithms visually.
- Write pseudocode to outline algorithms in a structured, human-readable format.
- Engage in algorithmic activities, such as design and evaluation techniques.
- Conduct dry runs of flowcharts and pseudocode to manually verify their correctness.
- Understand the concept and importance of LARP (Logic of Algorithms for Resolution of Problems).
- Implement LARP activities to practice writing algorithms and drawing flowcharts.
- Identify different types of errors in algorithms, including syntax errors, logical errors, and runtime errors.
- Apply debugging techniques to find and fix errors in algorithms.
- Recognize common error messages encountered during LARP and learn how to address them.
- Demonstrate problem-solving skills by applying computational thinking principles to real-world scenarios.
- Evaluate the efficiency of different algorithms and improve them based on performance analysis.



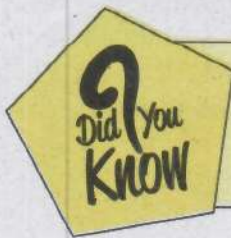
## Introduction

Introduction Computational thinking is an essential skill that enables individuals to solve complex problems using methods that align with processes involved in computer science. This chapter begins by defining computational thinking and breaking it down into its fundamental components: decomposition, pattern recognition, abstraction, and algorithms. These components are essential for simplifying complicated problems, identifying patterns that can lead to solutions, focusing on relevant details while ignoring unnecessary ones, and creating step-by-step procedures for solving problems. Understanding these concepts is not only beneficial for computer scientists but also for anyone looking to improve their problem-solving skills across various fields.

In addition to defining computational thinking, this chapter explores the principles that guide it, such as understanding the problem at hand, simplifying it to make it more manageable, and selecting the best solution design. The chapter introduces different methods for designing algorithms, including the use of flowcharts and pseudocode, and explains how to distinguish between these two approaches. Furthermore, it emphasizes the importance of practicing algorithm design and evaluation through hands-on activities like LARP (Logic of Algorithms for Resolution of Problems). Lastly, the chapter covers essential aspects of error identification and debugging, providing techniques for recognizing and fixing common errors encountered during the implementation of algorithms. By mastering these skills, students will be well-equipped to tackle a wide range of computational problems efficiently and effectively.

### 7.1 Definition of Computational Thinking

Computational Thinking (CT) is a problem-solving process that involves a set of skills and techniques to solve complex problems in a way that can be executed by a computer. This approach can be used in various fields beyond computer science, such as biology, mathematics, and even daily life.



Computational thinking is not limited to computer science. It is used in everyday problem solving, such as planning a trip or organizing tasks.

Let's break down computational thinking into its key components:



### 7.1.1 Decomposition

Decomposition is the method of breaking down a complicated problem into smaller, more convenient components.

**Decomposition** is an important step in computational thinking. It involves dividing a complex problem into smaller, manageable tasks. Let's take the example of building a birdhouse. This task might look tough at first, but if we break it down, we can handle each part one at a time.

Here's how we can decompose the task of building a birdhouse. Figure 7.1 shows the decomposed tasks for building a birdhouse.

- **Design the Birdhouse:** Decide on the size, shape, and design. Sketch a plan and gather all necessary measurements.
- **Gather Materials:** List all the materials needed such as wood, nails, paint, and tools like a hammer and saw.
- **Cut the Wood:** Measure and cut the wood into the required pieces according to the design.
- **Assemble the Pieces:** Follow the plan to assemble the pieces of wood together to form the structure of the birdhouse.
- **Paint and Decorate:** Paint the birdhouse and add any decorations to make it attractive for birds.
- **Install the Birdhouse:** Find a suitable location and securely install the birdhouse where birds can easily access it.

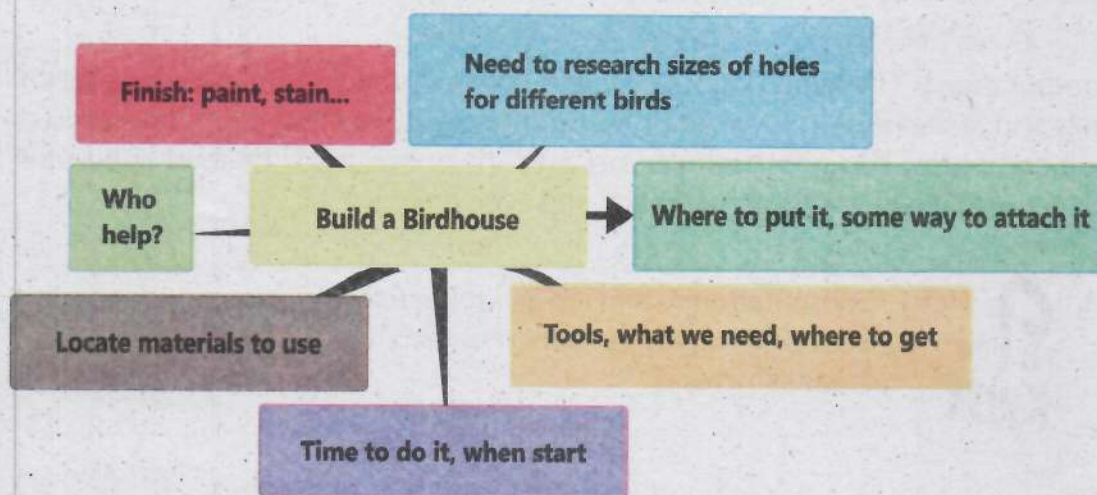


Figure 7.1: Building a Birdhouse



### Class activity

#### Decompose a Task

Think of a complex task you do regularly, like organizing a school event or cooking a meal. Break it down into smaller, manageable parts. Write down each step and discuss with your classmates how decomposition makes the task easier to handle.

#### 7.1.2 Pattern Recognition

Pattern recognition involves looking for similarities or patterns among and within problems. For instance, if you notice that you always forget your homework on Mondays, you might recognize a pattern and set a reminder specifically for Sundays.

Pattern recognition is an essential aspect of computational thinking. It involves identifying and understanding regularities or patterns within a set of data or problems. Let's consider the example of recognizing patterns in the areas of squares.

The upper row in Figure 7.2 represents the side lengths of squares, ranging from 1 to 7. The lower row shows the corresponding areas of these squares. Here, we can observe a pattern in how the areas increase.

- Side Length 1: Area =  $1^2 = 1$
- Side Length 2: Area =  $2^2 = 4$  ( $1 + 3$ )
- Side Length 3: Area =  $3^2 = 9$  ( $1 + 3 + 5$ )
- Side Length 4: Area =  $4^2 = 16$  ( $1 + 3 + 5 + 7$ )
- Side Length 5: Area =  $5^2 = 25$  ( $1 + 3 + 5 + 7 + 9$ )
- Side Length 6: Area =  $6^2 = 36$  ( $1 + 3 + 5 + 7 + 9 + 11$ )
- Side Length 7: Area =  $7^2 = 49$  ( $1 + 3 + 5 + 7 + 9 + 11 + 13$ )

We can see that the area of each square can be calculated by adding consecutive odd numbers. For example, the area of a square with a side length of 3 can be found by adding the first three odd numbers:  $1 + 3 + 5 = 9$ .

**Visual/Numerical Pattern**  
Goes up by 1

	+1	+1	+1	+1	+1	+1	
Side	1	2	3	4	5	6	7
Area	1	4	9	16	25	36	49
		+3	+5	+7	+9	+11	+13

Figure 7.2: Pattern in areas of squares with sides from 1 to 7



### Class activity

Create a table with side lengths from 1 to 10. Calculate the areas of the squares using the pattern of adding consecutive odd numbers. Verify your results by squaring the side lengths and see if the pattern holds.

### 7.1.3 Abstraction

Abstraction is a fundamental concept in problem solving, especially in computer science. It involves simplifying complex problems by breaking them down into smaller, more manageable parts, and focusing only on the essential details while ignoring the unnecessary ones. This helps in understanding, designing, and solving problems more efficiently.

- **Definition:** Abstraction is the process of hiding the complex details while exposing only the necessary parts. It helps reduce complexity by allowing us to focus on the high-level overview without getting lost in the details.
- **Example:** Making a Cup of Tea - **High-level Steps:** 1. Boil water. 2. Add tea leaves or a tea bag. 3. Steep for a few minutes. 4. Pour into a cup and add milk/sugar if desired.

### Tidbits

When solving complex problems, try to break them down into smaller parts and focus on the main steps. This will help you understand the problem better and find a solution more easily. By using abstraction, we can tackle complex problems by dealing with them at a higher level.

### 7.1.3 Algorithms

An algorithm is a step-by-step collection of instructions to solve a problem or complete a task similar to following a recipe to bake a cake..

An **algorithm** is a precise sequence of instructions that can be followed to achieve a specific goal, like a recipe or a set of directions that tells you exactly what to do and in what order.

#### HOW TO BAKE A CAKE?

- 1) Preheat the oven
- 2) Gather the ingredients
- 3) Measure out the ingredients
- 4) Mix together the ingredients to make the batter
- 5) Grease a pan
- 6) Pour the batter into the pan
- 7) Put the pan in the oven
- 8) Set a timer
- 9) When the timer goes off, take the pan out of the oven
- 10) Enjoy!



Figure 7.3: Algorithm example: Recipe to bake a cake



- **Example 1: Baking a Cake:** In Figure 7.3, we see a recipe for baking a cake. The recipe provides a list of ingredients and step-by-step instructions to mix them and bake the cake. This is an example of an algorithm because it outlines a clear sequence of steps to achieve the goal of baking a cake.
- **Example 2: Planting a Tree:** Here is a simple algorithm to plant a tree, an activity that can be very meaningful and beneficial:
  1. Choose a suitable spot in your garden.
  2. Dig a hole that is twice the width of the tree's root ball.
  3. Place the tree in the hole, making sure it is upright.
  4. Fill the hole with soil, pressing it down gently to remove air pockets.
  5. Water the tree generously to help it settle.
  6. Add mulch around the base of the tree to retain moisture.
  7. Water the tree regularly until it is established.

This algorithm gives clear instructions on how to plant a tree, making it easy to follow for anyone.

### Class activity

Let's create an algorithm! Think of something you do every day, like brushing your teeth or packing your school bag. Write down the steps you follow, one by one. Share your algorithm with your class and see if your friends can follow it!



Did you know that algorithms are not just used in computers? They are everywhere! When you follow directions to your friend's house or play a board game with rules, you are using algorithms. Algorithms help us solve problems logically.

### Class activity

- Outline an algorithm for applying to the Board of Intermediate and Secondary Education (BISE) for 9<sup>th</sup> Grade Examination.

### Algorithm Challenge

- Work in pairs to create an algorithm for a common task, such as making a sandwich or getting ready for school. Write down each step clearly, then exchange algorithms with another pair. Follow their algorithm exactly as written and see if you can complete the task.



## 7.2 Principles of Computational Thinking

Computational thinking involves several key principles that guide the process of problem-solving in a structured manner.

### 7.2.1 Problem Understanding

Understanding a problem involves identifying the core issue, defining the requirements, and setting the objectives. Understanding the problem is the first and most important step in problem-solving, especially in computational thinking. This involves thoroughly analyzing the problem to identify its key components and requirements before attempting to find a solution.

"If I had an hour to solve a problem I'd spend 55 minutes thinking about the problem and 5 minutes thinking about solutions". — **Albert Einstein**

#### Importance of Problem Understanding:

- **Clarity and Focus:** By fully understanding the problem, you gain clarity on what needs to be solved. This helps you focus on the right aspects without getting distracted by irrelevant details.
- **Defining Goals:** Proper understanding of the problem allows you to define clear and achievable goals. You can determine what the final outcome should look like and set specific objectives to reach that outcome.
- **Efficient Solutions:** When you comprehend the problem well, you can devise more efficient and effective solutions. You can choose the best methods and tools to address the problem, saving time and resources.
- **Avoiding Mistakes:** By thoroughly understanding the problem, you can avoid common pitfalls and mistakes. Misunderstanding the problem can lead to incorrect solutions and wasted effort.

#### Example: Building a School Website

Imagine you are asked to build a website for your school. Before jumping into coding, you need to understand the problem:

1. **Identify Requirements:** What features does the website need? For example, pages for news, events, class schedules, and contact information.
2. **User Needs:** Who will use the website? Students, teachers, parents? Understanding your audience helps in designing user-friendly interfaces.
3. **Technical Constraints:** What resources and tools are available? Do you have access to a web server and the necessary software?

By understanding these aspects, you can plan and build a website that meets the needs of your school community.



Always take time to thoroughly understand a problem before starting to solve it. Ask questions, gather information, and clarify any doubts. This foundational step will lead to better and more effective solutions.

### 7.2.2 Problem Simplification

Simplifying a problem involves breaking it down into smaller, more manageable sub-problems. Example: To design a website, break down the tasks into designing the layout, creating content, and coding the functionality.

### 7.2.3 Solution Selection and Design

Choosing the best solution involves evaluating different approaches and selecting the most efficient one. Designing the solution requires creating a detailed plan or algorithm.

## 7.3 Algorithm Design Methods

Algorithm design methods provide a range of tools and techniques to tackle various computational problems effectively. Each method has its strengths and weaknesses, making it suitable for different types of problems. Understanding different methods allows one to choose the most appropriate approach for a given problem, leading to more efficient and elegant solutions. Let's discuss two of these methods.

### 7.3.1 Flowcharts

Flowcharts are visual representations of the steps in a process or system, depicted using different symbols connected by arrows. They are widely used in various fields, including computer science, engineering, and business, to model processes, design systems, and communicate complex workflows clearly and effectively.

#### 7.3.1.1 Importance of Flowcharts

- **Clarity:** Flowcharts provide a clear and concise way to represent processes, making them easier to understand at a glance.
- **Communication:** They are excellent tools for communicating complex processes to a wide audience, ensuring everyone has a common understanding.
- **Problem Solving:** Flowcharts help identify bottlenecks and inefficiencies in a process, aiding in problem-solving and optimization.
- **Documentation:** They serve as essential documentation for systems and



processes, which is useful for training and reference purposes.



The first standardized flowchart symbols were developed in 1947 by the American National Standards Institute (ANSI).

### 7.3.1.2 Flowchart Symbols

Flowchart symbols are visual representations used to illustrate the steps and flow of a process or system as shown in Table 7.1.






Symbol	Name	Description
	Oval (Terminal)	Represents the start or end of a process. Often labeled as "Start" or "End."
	Rectangle (Process)	Represents a process, task, or operation that needs to be performed.
	Parallelogram (Input/Output)	Represents data input or output (e.g., reading input from a user or displaying output on a screen).
	Diamond (Decision)	Represents a decision point in the process where the flow can branch based on a yes/no question or true/false condition.
	Arrow (Flowline)	Shows the direction of flow within the flowchart, connecting the symbols to indicate the sequence of steps.

Table 7.1: Flowchart symbols



Flowcharts were popularized by computer scientists such as John von Neumann and Herman Goldstine in the early days of computing.

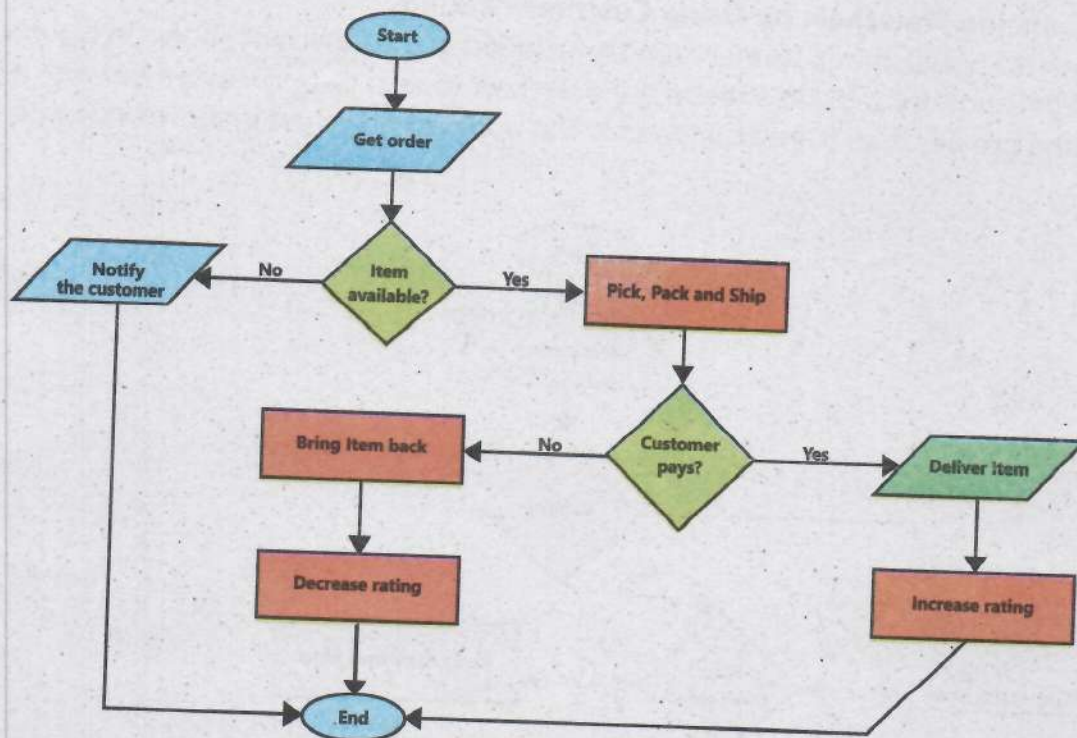


Figure 7.4: Flowchart of the Shop Order Process

### Class activity

Create a flowchart for a daily routine activity, such as getting ready for school. Include decision points like choosing what to wear based on the weather.

**Example:** A Shop Near Your House: Suppose a shop takes orders via cell phone messages. The flowchart in Figure 7.4 outlines the order processing steps. The input is the order, and the outputs are item delivery or a notification to the customer if the item is unavailable.



Decisions are made regarding item availability and customer payment. If the customer does not accept the item or make the payment, the item is returned to the shop, and the customer rating is decreased by 1. The customer's rating increases by 1 if they pay for the item. If the item is unavailable, the shop notifies the customer; otherwise, the shop picks, packs, and ships the item.

### Enhancing Flowchart by Using Customer Rating

Note that while the customer rating is included in the flowchart shown in Figure 7.4, it is not utilized. Let's revise the flowchart to ensure only customers with a rating greater than 0 are attended to. The updated flowchart is shown in Figure 7.5.

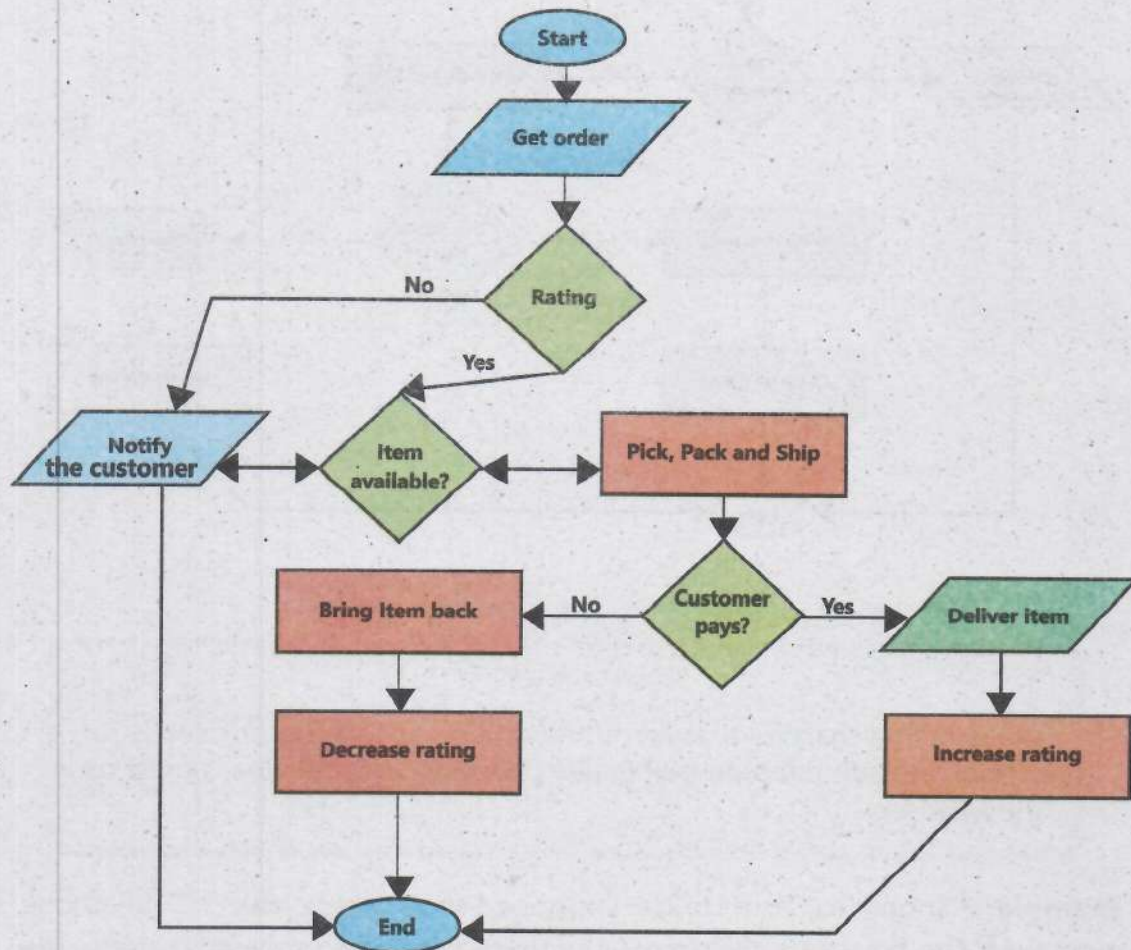


Figure 7.5: Flowchart of the shop using customer's rating



### Class activity

Modify Figure 7.5 to ensure that customer ratings are within the valid range of 0 to 5, inclusive. Ratings cannot be negative or exceed 5

**Example:** A flowchart for a login system showing steps such as inputting a username and password, verifying credentials, and granting access shown in Figure 7.6. A user can make a maximum of five attempts.

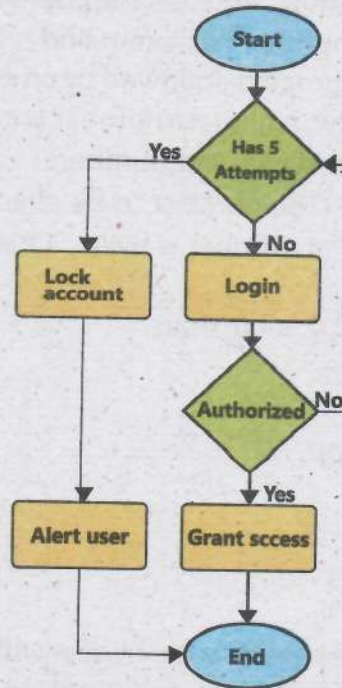


Figure 7.6: Flowchart for a login system

### Class activity

Draw a flowchart for selecting the school cricket team. The team can have a maximum of 11 players, and each player must have parental permission.

#### 7.3.2 Pseudocode

Pseudocode is a method of representing an algorithm using simple and informal language that is easy to understand. It combines the structure of programming



clarity with the readability of plain English, making it a useful tool for planning and explaining algorithms.

### What is Pseudocode?

Pseudocode is not actual code that can be run on a computer, but rather a way to describe the steps of an algorithm in a manner that is easy to follow. It helps programmers and students focus on the logic of the algorithm without worrying about the syntax of a specific programming language.

#### Example-1

Determining whether a number is even or odd is a fundamental task in programming and computer science. An even number is divisible by 2 without any remainder, whereas an odd number has a remainder of 1 when divided by 2. Below is the pseudocode for this process, followed by an explanation.

**Algorithm 1** Pseudocode for determining if a number is even or odd.

```
1:  Procedure CheckEvenOdd(number)
2:  Input: number {The number to be checked}
3:  Output: "Even" if number is even, "Odd" if number is odd
4:  Begin
5:      if (number % 2 == 0) then
6:          print "Even"
7:      else
8:          print "Odd"
9:      End if
10: End
```

#### Explanation

- 1. Procedure Declaration:** The pseudocode begins with the declaration of the procedure 'CheckEvenOdd' which takes a single input, 'number'.
- 2. Input:** The procedure accepts a variable 'number' which is the integer to be checked.
- 3. Output:** The procedure outputs "Even" if the number is even, and "Odd" if the number is odd.
- 4. Begin:** Mark the start of the procedure.
- 5. Condition Check:** The condition 'if (number % 2 == 0)' checks if the remainder of the number when divided by 2 is zero. The modulo operator '%' is used for this purpose.
- 6. Even Case:** If the condition is true, the procedure prints "Even".
- 7. Odd Case:** If the condition is false, the procedure prints "Odd".
- 8. End:** Marks the end of the procedure.



### Example-2

Determining whether a number is prime is a fundamental task in number theory and computer science. A prime number is a natural number greater than 1 that has no positive divisors other than 1 and itself. Below is the pseudocode for this process, followed by an explanation.

**Algorithm 2** Pseudocode for determining if a number is prime.

```
1:  Procedure Is Prime(number)
2:    Input: number {The number to be checked}
3:    Output: True if number is prime, False otherwise
4:    Begin
5:      if (number <= 1) then
6:        return False
7:      end if
8:      for i from 2 to sqrt(number) do
9:        if (number % i == 0) then
10:         return False
11:        end if
12:      end for
13:      return True
14:    End
```

### Explanation

1. **Procedure Declaration:** The pseudocode begins with the declaration of the procedure 'IsPrime' which takes a single input, 'number'.
2. **Input:** The procedure accepts a variable 'number', the integer to be checked.
3. **Output:** The procedure will output 'True' if the number is prime, and 'False' otherwise.
4. **Begin:** Mark the start of the procedure.
5. **Initial Check:** The condition 'if (number <= 1)' checks if the number is less than or equal to 1. If true, the procedure returns 'False' because numbers less than or equal to 1 are not prime.
6. **Loop Through Possible Divisors:** The 'for' loop iterates from 2 to the square root of the integer. This is because a greater factor of the number is a multiple of a previously tested smaller factor.
7. **Divisibility Check:** Inside the loop, the condition 'if (number % i == 0)'



checks if the number is divisible by 'i' without a remainder. If true, the procedure returns 'False' because the number has a divisor other than 1 and itself.

8. **Prime Confirmation:** If no divisors are found in the loop, the procedure returns 'True', confirming the number is prime.
9. **End:** Marks the end of the procedure.

### Class activity

**Create Your Own Pseudocode:** Divide the students into small groups and assign each group a different simple problem, such as finding the maximum number in a list or calculating the factorial of a number. Ask them to write the pseudocode for their assigned problem and then present it to the class.



Pseudocode is often used in software development before writing the actual code to ensure that the logic is sound and to facilitate communication between team members who may be using different programming languages.

### Why Use Pseudocode?

Using pseudocode has several benefits:

- **Clarity:** It helps in understanding the logic of the algorithm without worrying about syntax.
- **Planning:** It allows programmers to outline their thoughts and plan the steps of the algorithm.
- **Communication:** It is a universal way to convey the steps of an algorithm, making it easier to discuss with others.

### 7.3.3 Differentiating Flowcharts and Pseudocode

Flowcharts and pseudocode are both tools used to describe algorithms, but they do so in different ways. Understanding their differences can help you decide which method is more suitable to use for your scenario.



Pseudocode	Flowcharts
<ul style="list-style-type: none"> <li>• Pseudocode uses plain language and structured format to describe the steps of an algorithm.</li> <li>• It is read like a story, with each step is written out sequentially.</li> <li>• Pseudocode communicates the steps in a detailed, narrative-like format.</li> <li>• It is particularly useful for documenting algorithms in a way that can be easily converted into actual code in any programming language.</li> </ul>	<ul style="list-style-type: none"> <li>• Flowcharts use graphical symbols and arrows to represent the flow of an algorithm.</li> <li>• It is like watching a movie, where each symbol (such as rectangles, diamonds, and ovals) represents a different type of action or decision, and arrows indicate the connection and direction of the flow.</li> <li>• Flowchart communicates the process in a visual format, which can be more intuitive for understanding the overall flow and structure.</li> <li>• They are useful for identifying the steps and decisions in an algorithm at a glance.</li> </ul>

Table 7.2 Difference between Pseudocode and Flowcharts

### Example-3

**Algorithm 3** presents the pseudocode for checking a valid username and password.

1. **Procedure** CheckCredentials(username, password)
2. **Input:** username, password
3. **Output:** Validity message
4. **Begin**
5. validUsername = "user123" {Replace with the actual valid username}
6. validPassword = "pass123" {Replace with the actual valid password}
7. if (username == validUsername) then



```
8:      if (password == validPassword) then
9:          print "Login successful"
10:     else
11:         print "Invalid password"
12:     end if
13: else
14:     print "Invalid username"
15: end if
16: End
```

## 7.4 Algorithmic Activities

### 7.4.1 Design and Evaluation Techniques

Techniques to essential algorithms are essential to understand how efficiently they solve problems. In this section, we will explore different techniques for evaluating algorithms, focusing on their time and space complexities.

#### 7.4.1.1 Time Complexity

Time Complexity measures how fast or slow an algorithm performs. It shows how the running time of an algorithm changes as the size of the input increases. Here's an easy way to understand it:

Imagine you have a list of names, and you want to find a specific name. If you have 10 names, it might only take a few seconds to look through the list. But what if you have 100 names? Or 1,000 names? The time it takes to find the name increases as the list gets longer. Time complexity helps us understand this increase.



Time complexity is usually expressed using Big O notation, like  $O(n)$ ,  $O(\log n)$ , or  $O(n^2)$ . It helps us compare different algorithms to see which one is faster!

#### Tidbits

When writing an algorithm, consider how many steps it takes to complete the task. Fewer steps means a faster algorithm!



### Class activity

Think of a simple task, like finding the largest number in a list. Write down the steps you would take to complete this task. Now, imagine the list has 10 numbers, then 100 numbers. How do the steps change?



Some algorithms can perform the same task much faster than others. For example, sorting a list of 100 items might take one algorithm 1 second and another algorithm 10 seconds!

#### 7.4.1.2 Space Complexity

Space complexity measures the amount of memory an algorithm uses relative to input size. It is essential to consider both the memory required for the input and any extra memory used by the algorithm.

Designing and evaluating algorithms involves activities like dry runs and simulations to ensure they work as intended.

### 7.5 Dry Run

A dry run involves manually going through the algorithm with sample data to identify any errors.

#### 7.5.1 Dry Run of a Flowchart

A dry run of a flowchart involves manually walking through the flowchart step-by-step to understand how the algorithm works without using a computer. This helps identify any logical errors and understand the flow of control.

### Example: Calculating the Sum of Two Numbers

Consider the flowchart given in figure 7.7 for adding two numbers:

**Steps to dry run this flowchart:**

1. Start
2. Input the first number (e.g., 3)
3. Input the second number (e.g., 5)
4. Add the two numbers ( $3 + 5 = 8$ )

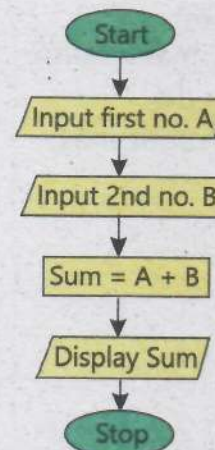


Figure 7.7: Flowchart for adding two numbers

### Dry Run a Flowchart

Draw a flowchart for finding the largest of two numbers. Perform a dry run for the numbers 7 and 4. Write down each step and the values of variables.

### Class activity



5. Output the result (8)
6. Stop

### 7.5.2 Dry Run of Pseudocode

A dry run of pseudocode involves manually simulating the execution of the pseudocode line-by-line.

This helps in verifying the logic and correctness of the algorithm.

#### Example: Finding the Maximum of Two Numbers

Consider the pseudocode for finding the maximum of two numbers:



Did you know that different algorithms can solve the same problem more efficiently? For instance, one algorithm might quickly find the highest marks in a list, while another might take much longer. Learning how to evaluate and choose the best algorithm is a key skill in computer science!

#### Algorithm 4 FindMax

1. Input: num1, num2
2. if num1 > num2 then
3.     max = num1
4. else
5.     max = num2
6. end if
7. Output: max

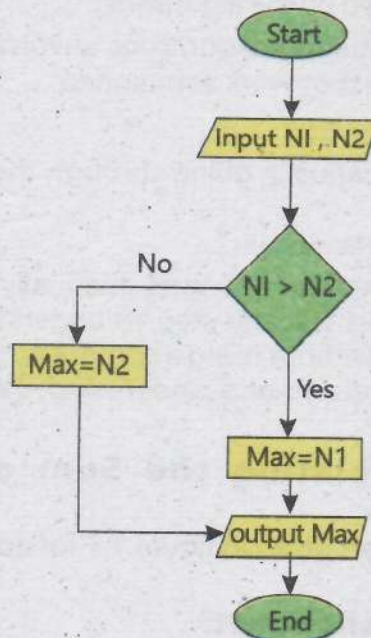


Figure 7.8: Flowchart for finding maximum of two numbers

#### Steps to dry run this pseudocode:

1. Input num1 and num2 (e.g., 10 and 15)
2. Check if num1 > num2 (10 > 15: False)
3. Since the condition is False, max = num2 (max = 15)
4. Output max (15)





- Dry running your code or algorithm helps catching errors early in the development process, saving time and effort.
- Many professional programmers and computer scientists use dry running as a debugging technique to ensure their algorithms work correctly!

### 7.5.3 Simulation

Simulation is we use of computer programs to create a model of a real-world process or system. This helps us understand how things work by testing different ideas or algorithms without needing to try them out in real life.

#### Why Use Simulation?

1. **Testing Algorithms:** We can use simulation to see how well an algorithm works with different types of data. For example, if we want to test a new way to sort numbers, we can simulate it with different sets of numbers to see how fast it is.
2. **Exploring Scenarios:** Simulation allows us to create many different situations to see what happens. For example, in a science experiment about plant growth, we can simulate different amounts of water or sunlight to find out which conditions help plants grow best.

#### Benefits of Simulation

- **Cost-Effective:** It is often cheaper and faster to run simulations than to conduct real experiments.
- **Safe:** We can test dangerous situations, like a fire in a building, without putting anyone at risk.
- **Repeatable:** We can run the same simulation multiple times with different settings to observe how things change.

#### Examples of Simulation

1. **Weather Forecasting:** Meteorologists use simulations to predict the weather. They input data about temperature, humidity, and wind speed into a computer model to see how the weather might change over the next few days.
2. **Traffic Flow:** City planners can simulate traffic to see how changes to roads or traffic lights might affect the flow of cars. This helps them design better roads and reduce traffic jams.



## 7.6 Introduction to LARP (Logic of Algorithms for Resolution of Problems)

LARP stands for Logic of Algorithms for resolution of Problems. It is a fun and interactive way to learn how algorithms work by actually running them and seeing the results. Think of it as a playground where you can experiment with different algorithms and understand how they process data.



For the latest versions and updates of LARP software, check trusted educational and coding platforms, or search for "LARP software download" on your favorite search engine.

### 7.6.1 Why is LARP Important?

LARP helps you:

- Understand how algorithms work. For instance, refer to Figure 7.9, which illustrates an algorithm designed to determine the applicability of tax on the annual salary of a person.
- See the effect of different inputs on the output.
- Practice writing and improving your own algorithms.

### 7.6.2 Writing Algorithms

Writing algorithms using LARP involves a structured and simplified approach to developing logical solutions for computational problems. LARP employs a clear syntax that begins with a START command and ends with an END command, ensuring that each step of the algorithm is easy to follow. Within this framework, instructions are provided in a straightforward manner, such as using WRITE to display messages, READ to input values, and conditional statements like IF...THEN...ELSE to handle decision-making processes. By breaking down complex problems into manageable steps, LARP allows learners to focus on the logical flow of the algorithm without getting stuck on complex coding syntax. This method not only aids in understanding the fundamental concepts of algorithm design but also enhances problem-solving skills by encouraging clear and logical thinking.

Here's an example of a simple algorithm to check if a number is even or odd:



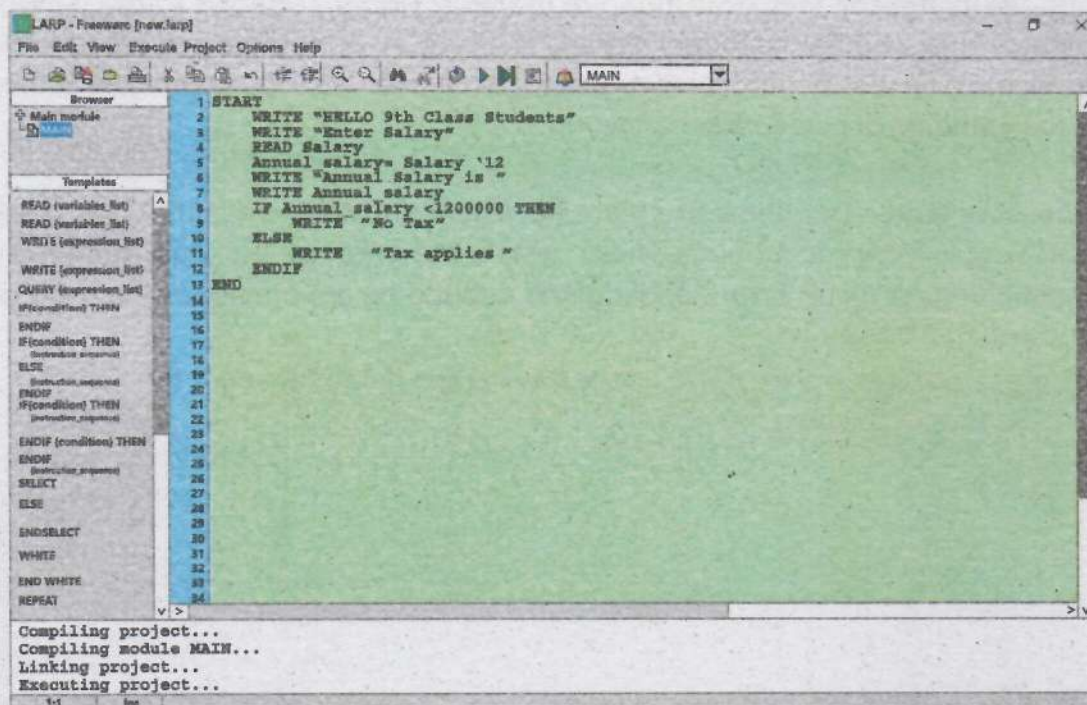


Figure 7.9: LARP Software

```

START
  WRITE "Enter a number"
  READ number
  IF number % 2 == 0 THEN
    WRITE "The number is even"
  ELSE
    WRITE "The number is odd"
  ENDIF
END
  
```

### 7.6.3 Drawing Flowcharts in LARP

Drawing flowcharts in LARP involves visually representing the algorithm's steps using standard flowchart symbols such as rectangles for processes, diamonds for decisions, and parallelograms for input/output operations. Once the flowchart is created, it can be executed in LARP by translating the flowchart into LARP syntax, which uses straightforward commands like START, WRITE, READ, IF...THEN...ELSE, and END. This process allows students to visualize the logic of their algorithm



and see its step-by-step execution. For example, Figure 7.9 shows a flowchart for determining whether a student's grade is above 'A' or not. We can execute the flowchart to verify its correctness. This hands-on approach reinforces understanding of how a flowchart works.

## 7.7 Error Identification and Debugging

When we write algorithms or create flowcharts in LARP, we sometimes make mistakes called errors or bugs. These mistakes can prevent our algorithms from functioning correctly. Error handling and debugging are processes that help us find and fix these errors.

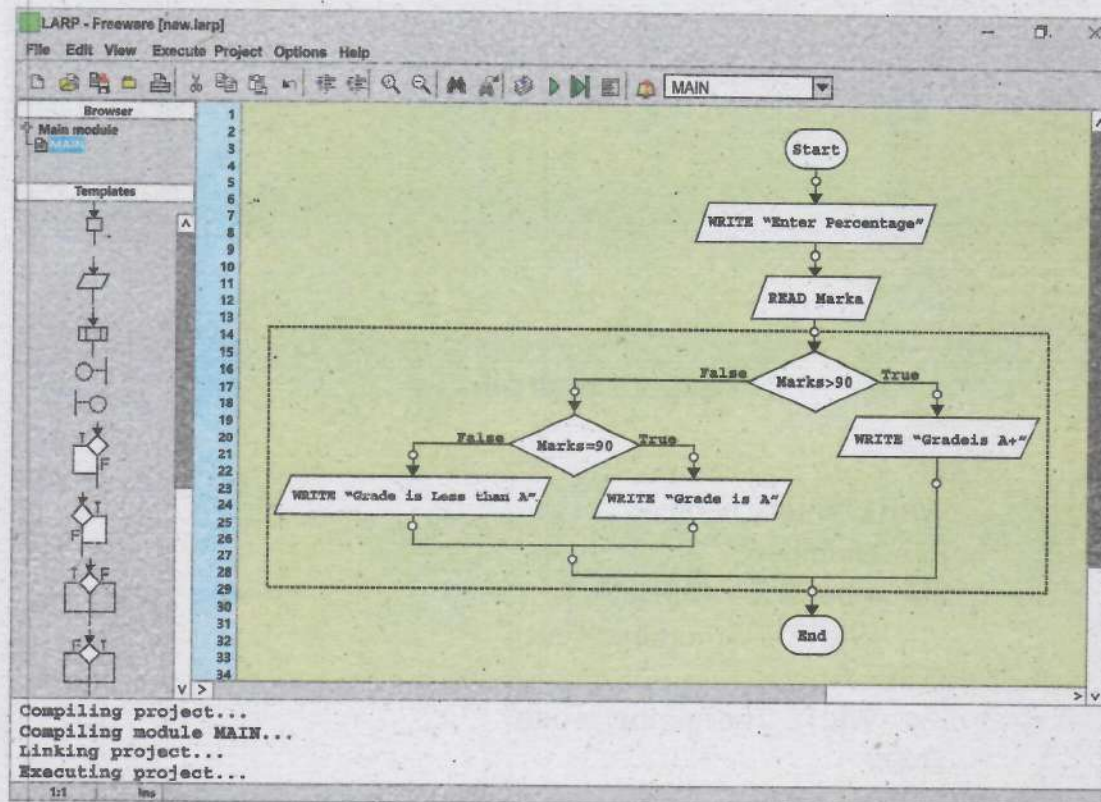


Figure 7.10: Flowchart in LARP

### 7.7.1 Types of Errors

There are three main types of errors you might encounter:

- **Syntax Errors:** These occur when we write something incorrectly in our algorithm or flowchart. For example, missing a step or using the wrong symbol.
- **Runtime Errors:** These happen when the algorithm or flowchart is being



executed. For example, trying to perform an impossible operation, such as dividing by zero.

- **Logical Errors:** These are mistakes in the logic of the algorithm that cause it to behave incorrectly. For example, using the wrong condition in a decision step.



Syntax errors are the easiest to find because the LARP tool usually points them out. However, logical errors are the hardest to find because the algorithm still runs but does not procedure correct answers.

### 7.7.2 Debugging Techniques

Debugging is the process of finding and fixing errors in an algorithm or flowchart. Here are some common debugging techniques:

- **Trace the Steps:** Go through each step of your algorithm or flowchart to see identity where it goes wrong.
- **Use Comments:** Write comments or notes in your algorithm to explain what each part is supposed to do. This can help you spot mistakes.
- **Check Conditions:** Ensure that all conditions in decision steps are correct.
- **Simplify the Problem:** Break down the algorithm into smaller parts and test each part separately.

#### Tidbits

Always read error messages carefully. They often tell you exactly where the problem is.

### 7.7.3 Common Error Messages in LARP

Here are some common error messages you might see in LARP and what they mean:

- **Missing Step** - You probably forgot to include an important step in your algorithm.
- **Undefined Variable** - You are using a variable that hasn't been defined yet.
- **Invalid Operation** - You are trying to perform an operation that is not allowed, like dividing by zero.



### Class activity

Create a simple flowchart in LARP that calculates the average of three numbers. Introduce a syntax error, a runtime error, and a logical error in your flowchart. Then, try to fix them using the debugging techniques we discussed.

**Did You Know**

The term "debugging" comes from an actual bug—a moth—that was found causing problems in an early computer. The moth was removed, and the process was called "debugging"

### Summary

- Computational thinking is important skill that enables individuals to solve complex problems using methods that mirror the processes involved in computer science.
- Decomposition is the process of breaking down a complex problem into smaller, more manageable parts.
- Pattern recognition involves looking for similarities or patterns among and within problems.
- Abstraction involves simplifying complex problems by breaking them down into smaller, more manageable part, and focusing only on the essential details while ignoring the unnecessary ones.
- An algorithm is a step-by-step set of instructions to solve a problem or complete a task.
- Understanding the problem is the first and most important step in problem-solving, especially in computational thinking.
- Simplifying a problem involves breaking it down into smaller, more manageable sub-problems.
- Choosing the best solution involves evaluating different approaches and selecting the most efficient one.
- Flowcharts are visual representations of the steps in a process or system, depicted using different symbols connected by arrows.
- Pseudocode is a way of representing an algorithm using simple and informal language that is easy to understand. It combines the structure of programming languages with the readability of plain English, making it a useful tool for planning and explaining algorithms.
- Time Complexity is a way to measure how fast or slow an algorithm performs. It tells us how the running time of an algorithm changes as the



size of the input increases.

- Space complexity measures the amount of memory an algorithm uses in relation to the input size. It is important to consider both the memory needed for the input and any additional memory used by the algorithm.
- A dry-run involves manually going through the algorithm with sample data to identify any errors.
- Simulation is when we use computer programs to create a model of a real-world process or system.
- LARP stands for logic of Algorithm for Resolution of Problems. It is a fun and interactive way to learn how algorithms work by actually running them and seeing the results.
- Debugging is the process of finding and fixing errors in an algorithm or flowchart.

## EXERCISE

### Multiple Choice Questions

1. Which of the following best defines computational thinking?

- (a) A method of solving problems using mathematical calculations only.
- (b) A problem-solving approach that employs systematic, algorithmic, and logical thinking.
- (c) A technique used exclusively in computer programming.
- (d) An approach that ignores real-world applications.

2. Why is problem decomposition important in computational thinking?

- (a) It simplifies problems by breaking them down into smaller, more manageable parts.
- (b) It complicates problems by adding more details.
- (c) It eliminates the need for solving the problem.
- (d) It is only useful for simple problems.

3. Pattern recognition involves:

- (a) Finding and using similarities within problems
- (b) Ignoring repetitive elements
- (c) Breaking problems into smaller pieces
- (d) Writing detailed algorithms

4. Which term refers to the process of ignoring the details to focus on the main idea?

- |                   |                         |
|-------------------|-------------------------|
| (a) Decomposition | (b) Pattern recognition |
| (c) Abstraction   | (d) Algorithm design    |



5. Which of the following is a principle of computational thinking?  
(a) Ignoring problem understanding (b) Problem simplification  
(c) Avoiding solution design (d) Implementing random solutions
6. Algorithms are:  
(a) Lists of data  
(b) Graphical representations  
(c) Step-by-step instructions for solving a problem  
(d) Repetitive patterns
7. Which of the following is the first step in problem-solving according to computational thinking?  
(a) Writing the solution (b) Understanding the problem  
(c) Designing a flowchart (d) Selecting a solution
8. Flowcharts are used to:  
(a) Code a program  
(b) Represent algorithms graphically  
(c) Solve mathematical equations  
(d) Identify patterns
9. Pseudocode is:  
(a) A type of flowchart  
(b) A high-level description of an algorithm using plain language  
(c) A programming language  
(d) A debugging tool
10. Dry running a flowchart involves:  
(a) Writing the code in a programming language  
(b) Testing the flowchart with sample data  
(c) Converting the flowchart into pseudocode  
(d) Ignoring the flowchart details

### Short Questions

1. Define computational thinking.
2. What is decomposition in computational thinking?
3. Explain pattern recognition with an example.
4. Describe abstraction and its importance in problem-solving.
5. What is an algorithm?
6. How does problem understanding help in computational thinking?
7. What are flowcharts and how are they used?
8. Explain the purpose of pseudocode.
9. How do you differentiate between flowcharts and pseudocode?
10. What is a dry run and why is it important?
11. Describe LARP and its significance in learning algorithms.
12. List and explain two debugging techniques.



### Long Questions

1. Write an algorithm to assign a grade based on the marks obtained by a student. The grading system follows these criteria:
  - 90 and above: A+
  - 80 to 89: A
  - 70 to 79: B
  - 60 to 69: C
  - Below 60: F
2. Explain how you would use algorithm design methods, such as flowcharts and pseudocode, to solve a complex computational problem. Illustrate your explanation with a detailed example.
3. Define computational thinking and explain its significance in modern problem-solving. Provide examples to illustrate how computational thinking can be applied in different fields.
4. Discuss the concept of decomposition in computational thinking. Why is it important?
5. Explain pattern recognition in the context of computational thinking. How does identifying patterns help in problem-solving?
6. What is an abstraction in computational thinking? Discuss its importance and provide examples of how abstraction can be used to simplify complex problems.
7. Describe what an algorithm is and explain its role in computational thinking. Provide a detailed example of an algorithm for solving a specific problem, and draw the corresponding flowchart.
8. Compare and contrast flowcharts and pseudocode as methods for algorithm design. Discuss the advantages and disadvantages of each method, and provide examples where one might be preferred over the other.
9. Explain the concept of a dry run in the context of both flowcharts and pseudocode. How does performing a dry run help in validating the correctness of an algorithm?
10. What is LARP? Discuss its importance in learning and practicing algorithms.
11. How does LARP enhance the understanding and application of computational thinking principles? Provide a scenario where LARP can be used to improve an algorithm.



# UNIT 8

## Web Development with HTML, CSS, and JavaScript

### Student Learning Outcomes

By the end of this chapter, you will be able to:

- Understand JavaScript syntax and data types.
- Work with variables, operators, and functions in JavaScript.
- Handle events and user input with JavaScript.
- Create simple programs using JavaScript.
- Create HTML forms and style them.
- Use JavaScript to handle events with operators, variables, and functions.
- Develop static web pages.
- Apply HTML tags appropriately to create web pages.
- Create a basic HTML page.
- Add text, images, and links to a page.
- Create lists and tables.
- Apply styles to HTML elements.
- Work with fonts, colors, and backgrounds.
- Create web pages to display data in the paragraphs and lists.
- Familiarize students with CSS syntax.
- Create layouts with CSS.
- Add animations and transitions with CSS.
- Develop, test, and debug static web pages.
- Organize images and text effectively.
- Use JavaScript along with HTML to handle events using operators, variables, and functions.