

COMPUTER

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Primary Disciplinary Field(s): Computer Science, Information Technology, Electrical Engineering

1. Core Definition and Functionality

The term **computer** denotes an advanced electronic apparatus designed fundamentally for the systematic execution of complex calculations or operations. As derived from the foundational definitions in computer science and cybernetics, a computer is defined as a machine capable of obtaining, synthesizing, retaining, and pushing out data, strictly adhering to formalized, coded directions--known as programs or algorithms--to generate predictable and **deterministic results**. This functional definition encompasses four essential phases: input, processing, storage, and output. Input involves the acquisition of data or instructions from external sources; processing is the manipulation and execution of those coded instructions to transform the input data; storage involves the temporary or permanent retention of data and instructions; and output is the presentation of the processed information back to the user or to another system. The ability of the computer to manage these sequential operations with high speed and reliability is what distinguishes it as the central instrument of the modern technological landscape.

The defining characteristic that elevates the computer beyond simple calculating tools, such as early mechanical calculators, is its inherent programmability. This characteristic means the machine is not fixed to perform a single, rigid sequence of tasks, but rather can be dynamically reconfigured by changing the set of coded directions. These directions, written in various programming languages and compiled into machine code, dictate the exact logical steps the internal hardware must follow. This adherence to coded directives ensures that, given the same input and the same program, the resulting output will be identical every time, reinforcing the concept of **deterministic operation**. This deterministic nature is crucial for scientific modeling, financial transactions, and mission-critical systems where reliability and predictability are paramount requirements.

Furthermore, while often visualized as a single physical entity, the conceptual model of a computer is fundamentally based on its capacity for abstract representation and manipulation of information. Data, in this context, refers not merely to numbers but to any form of information--text, images, audio, or instructions--that can be encoded digitally, typically using the binary system. The computer's electronic components facilitate the rapid switching of electrical states to perform logical operations (AND, OR, NOT), which form the basis of all complex arithmetic and data transformation processes. Thus, the computer serves as a universal machine capable of simulating and executing any computable function, provided sufficient time and memory resources are available.

2. Etymology and Historical Development

The etymology of the term **computer** originates from the Latin verb *computare*, meaning "to reckon together" or "to calculate." Historically, prior to the mid-20th century, a "computer" referred almost exclusively to a human being, typically a woman, employed to perform repetitive mathematical calculations, often for astronomical, navigational, or actuarial tables. This human reliance on manual calculation was tedious and prone to error, driving early innovations toward mechanical aids. The first significant mechanical precursor was the Analytical Engine, conceptualized by Charles Babbage in the 1830s, which included components essential to modern computers, such as an arithmetic logic unit (ALU), memory, and input/output mechanisms. Ada Lovelace, recognizing the machine's capacity to process more than just numbers, is credited with writing what is considered the first algorithm intended to be carried out by a machine, thereby establishing the conceptual foundation of programming.

The transition from mechanical concepts to electro-mechanical devices marked the next major phase of development. Projects like the Atanasoff-Berry Computer (ABC) and the German Z3 machine demonstrated the practical application of electrical components for calculation in the late 1930s and early 1940s. However, the true birth of the modern electronic digital computer is often attributed to the development of the Electronic Numerical Integrator and Computer (**ENIAC**) during World War II, operational in 1945. ENIAC used vacuum tubes, which allowed for unprecedented speed, although it lacked stored program capability, requiring physical rewiring for new tasks. This era highlighted the critical need for a more flexible architecture that could separate hardware from the instruction set.

The seminal breakthrough arrived with the development of the **stored-program concept**, primarily formulated by John von Neumann, based on earlier work by Alan Turing. The Von Neumann architecture proposed that both the instructions (the program) and the data being processed should reside in the same memory space. This innovation dramatically simplified programming and enabled the creation of truly general-purpose machines, fundamentally defining the architecture used in nearly all computers today, from supercomputers to smartphones. Subsequent technological leaps, including the invention of the transistor in 1947, which replaced the bulky and unreliable vacuum tubes, and the creation of the integrated circuit (microchip) in the late 1950s, dramatically reduced the size, cost, and power consumption of computers, paving the way for mass production and the subsequent information revolution.

3. Key Architectural Components (Hardware and Software)

The functionality of a computer relies on a complex interplay between hardware (the physical components) and software (the coded instructions). At the heart of the system is the **Central Processing Unit (CPU)**, often referred to as the brain of the computer. The CPU is responsible for

executing the program instructions, performing arithmetic and logic operations (via the ALU), and managing the flow of data across the system (via the Control Unit). The speed and efficiency of the CPU, measured in clock cycles, determine the overall performance capability of the computer in synthesizing data and generating results. Modern CPUs incorporate multiple cores and advanced caching systems to handle parallel processing tasks efficiently.

Memory and storage constitute the component responsible for retaining data and instructions. **Random Access Memory (RAM)** is volatile primary storage used by the CPU to hold currently executing programs and the data they are actively manipulating, enabling rapid access necessary for efficient processing. In contrast, secondary storage devices, such as Hard Disk Drives (HDDs) and Solid State Drives (SSDs), offer non-volatile, long-term retention of operating systems, applications, and user files. The hierarchy of memory--from small, fast CPU caches to large, slow secondary storage--is engineered to optimize the balance between access speed and total capacity, critical for handling the massive datasets common in modern computation.

The critical link between the hardware platform and the user or application programs is the **operating system (OS)**. The OS is a collection of software that manages all the computer's resources, allocating memory, scheduling tasks, handling input and output operations, and providing a stable platform for application execution. Without the OS, the user would have to interact directly with the complex machine code, making modern computing virtually impossible for general users. Application software, the highest layer of the software stack, consists of the specific programs (e.g., word processors, browsers, games) that leverage the OS and hardware to perform specialized tasks required by the user, ultimately fulfilling the purpose of pushing out processed data in a usable format.

4. Operational Characteristics and Turing Completeness

A fundamental characteristic underpinning the operation of all modern digital computers is their inherent compliance with the theoretical model of computation established by Alan Turing in 1936: the Turing Machine. A machine is considered **Turing complete** if it can perform any calculation that a theoretical Turing machine can perform. This property is what grants the computer its universal power; any system that is Turing complete can, in principle, simulate any other Turing complete system. Modern instruction sets and programming languages are designed specifically to harness this completeness, ensuring that the machine is capable of executing any algorithm, however complex, provided the algorithm is logically sound and finite.

The execution of coded directions relies on the computer's ability to perform extremely fast, simple operations in sequence. An algorithm is translated into a series of fundamental machine instructions (e.g., load, store, add, jump). The Control Unit of the CPU fetches these instructions from memory one by one, decodes what action is required, and executes that action, often

involving the ALU. The speed at which this fetch-decode-execute cycle occurs, now measured in billions of cycles per second (Gigahertz), is what gives the computer its immense power to synthesize vast amounts of data almost instantaneously. The adherence to this strict sequential execution of coded directions is the mechanism by which the computer guarantees the deterministic nature of its results.

Moreover, the structure of the coded directions inherently incorporates conditional logic. Instructions such as "IF condition X is met, THEN execute instruction Y, ELSE execute instruction Z" allow the computer to make dynamic decisions based on the state of the input data or internal variables. This capacity for conditional branching is critical for moving beyond simple linear calculation and enabling complex, interactive programming, such as those found in operating systems, artificial intelligence, and network protocols. The seamless integration of high-speed execution, deterministic logic, and conditional branching defines the operational effectiveness of the computer in solving intricate problems across virtually all fields.

5. Classification and Types

Computers are classified based on their size, processing power, purpose, and domain of application, reflecting the diverse ways in which computation is utilized in society. At the highest echelon of power are **Supercomputers**, which are designed for maximum calculation speed, typically used for complex scientific and engineering problems such as climate modeling, molecular dynamics, and large-scale simulation. These machines often employ thousands of processors working in parallel and represent the cutting edge of computational capability, achieving speeds measured in petaflops.

Below supercomputers are **Mainframes**, which are high-performance machines optimized not necessarily for raw speed but for reliability, stability, and handling massive throughput of transaction processing (I/O operations). Mainframes remain vital in industries requiring continuous, high-volume processing, such as banking, government, and large-scale enterprise resource planning (ERP) systems. Their design emphasizes fault tolerance and the ability to serve thousands of concurrent users or processes simultaneously, functioning as central hubs for global operations.

The most common classifications are **Personal Computers (PCs)**--including desktops, laptops, and workstations--and Mobile Devices, which include tablets and smartphones. PCs are general-purpose machines designed for individual productivity, communication, and entertainment, representing the democratization of computing power introduced during the late 20th century. A specialized but crucial class is the **Embedded System**, which consists of computers integrated into non-computer devices (e.g., cars, smart appliances, industrial machinery). These systems are highly specialized, often resource-constrained, and designed to perform a dedicated function in

real-time, greatly outnumbering all other types of computers combined.

6. Significance and Impact

The development and widespread adoption of the computer represent arguably the most significant technological transformation since the industrial revolution. The capacity to automate complex tasks, manage vast datasets, and facilitate near-instantaneous global communication has fundamentally restructured economic activity, social interaction, and scientific inquiry. Economically, computers drive productivity gains through automation, supply chain optimization, and the creation of entirely new digital industries. The ability to simulate complex systems has drastically reduced the cost and time required for research and development across fields ranging from pharmaceuticals to aerospace engineering.

Socially, the computer, particularly in its networked form (the Internet), has dismantled traditional barriers of time and geography. It has created unprecedented access to information, transforming education, political discourse, and culture. The rise of social media and global connectivity, while presenting new challenges, is entirely reliant on the infrastructure provided by computer networks and processing power. The computer is no longer merely a tool for calculation but the primary medium through which modern society stores knowledge, conducts commerce, and communicates, acting as the foundation of the **Information Age**.

In science, the computer's role is transformative, establishing the field of computational science as a third paradigm of scientific discovery, alongside theoretical and experimental science. Disciplines such as bioinformatics, high-energy physics, and cosmology rely heavily on computational modeling to analyze observational data or simulate phenomena that are impossible or too costly to reproduce in a lab. The sheer speed and accuracy with which computers can synthesize and analyze data have accelerated the pace of discovery, ensuring that the computer remains an indispensable tool for human intellectual advancement.

7. Debates and Criticisms (Ethical and Social Implications)

Despite the profound benefits derived from computer technology, its pervasive integration into life has generated significant ethical, social, and political debates. One primary area of concern revolves around **data privacy and surveillance**. The computer's unmatched capability to obtain and retain vast amounts of personal data creates vulnerabilities for unauthorized access, misuse by corporations, and surveillance by state actors, leading to ongoing legislative efforts like the General Data Protection Regulation (GDPR) to assert individual control over digital footprints.

Another critical debate centers on the socioeconomic impact, specifically concerning **automation and job displacement**. As computers and robotic systems become capable of executing increasingly complex tasks, there are legitimate fears about the replacement of human labor in

sectors ranging from manufacturing to white-collar services. While technology often creates new jobs, the transition period and the necessity for massive workforce retraining present significant social friction. The resulting economic disparity is exacerbated by the **digital divide**, where lack of access to computer hardware, reliable connectivity, or digital literacy excludes marginalized populations from participation in the information economy.

Finally, the growing sophistication of computer systems in areas like Artificial Intelligence (AI) raises complex ethical dilemmas concerning autonomy and accountability. As AI systems are given greater control over critical decisions--such as medical diagnoses, financial transactions, or the operation of autonomous vehicles--questions arise regarding algorithmic bias, transparency in decision-making, and where ultimate responsibility lies when an autonomous system causes harm. Addressing these issues requires a careful balance between leveraging the computer's capacity for complex computation and establishing robust ethical frameworks to govern its application.

Further Reading

[Computer Science \(Wikipedia\)](#)

[Von Neumann Architecture \(Wikipedia\)](#)

[Turing Machine \(Wikipedia\)](#)

[Information Technology \(Wikipedia\)](#)