Technology Computers Ask the Chatbot a Question A computer might be described with deceptive simplicity as “an apparatus that performs routine calculations automatically.” Such a definition would owe its deceptiveness to a naive and narrow view of calculation as a strictly mathematical process. In fact, calculation underlies many activities that are not normally thought of as mathematical. Walking across a room, for instance, requires many complex, albeit subconscious, calculations. Computers, too, have proved capable of solving a vast array of problems, from balancing a checkbook to even—in the form of guidance systems for robots—walking across a room. Before the true power of computing could be realized, therefore, the naive view of calculation had to be overcome. The inventors who labored to bring the computer into the world had to learn that the thing they were inventing was not just a number cruncher, not merely a calculator. For example, they had to learn that it was not necessary to invent a new computer for every new calculation and that a computer could be designed to solve numerous problems, even problems not yet imagined when the computer was built. They also had to learn how to tell such a general problem-solving computer what problem to solve. In other words, they had to invent programming. They had to solve all the heady problems of developing such a device, of implementing the design, of actually building the thing. The history of the solving of these problems is the history of the computer. That history is covered in this section, and links are provided to entries on many of the individuals and companies mentioned. In addition, see the articles computer science and supercomputer. The earliest known calculating device is probably the abacus. It dates back at least to 1100 bce and is still in use today, particularly in Asia. Now, as then, it typically consists of a rectangular frame with thin parallel rods strung with beads. Long before any systematic positional notation was adopted for the writing of numbers, the abacus assigned different units, or weights, to each rod. This scheme allowed a wide range of numbers to be represented by just a few beads and, together with the invention of zero in India, may have inspired the invention of the Hindu-Arabic number system. In any case, abacus beads can be readily manipulated to perform the common arithmetical operations—addition, subtraction, multiplication, and division—that are useful for commercial transactions and in bookkeeping. The abacus is a digital device; that is, it represents values discretely. A bead is either in one predefined position or another, representing unambiguously, say, one or zero. Calculating devices took a different turn when John Napier, a Scottish mathematician, published his discovery of logarithms in 1614. As any person can attest, adding two 10-digit numbers is much simpler than multiplying them together, and the transformation of a multiplication problem into an addition problem is exactly what logarithms enable. This simplification is possible because of the following logarithmic property: the logarithm of the product of two numbers is equal to the sum of the logarithms of the numbers. By 1624, tables with 14 significant digits were available for the logarithms of numbers from 1 to 20,000, and scientists quickly adopted the new labor-saving tool for tedious astronomical calculations. Most significant for the development of computing, the transformation of multiplication into addition greatly simplified the possibility of mechanization. Analog calculating devices based on Napier’s logarithms—representing digital values with analogous physical lengths—soon appeared. In 1620 Edmund Gunter, the English mathematician who coined the terms cosine and cotangent, built a device for performing navigational calculations: the Gunter scale, or, as navigators simply called it, the gunter. About 1632 an English clergyman and mathematician named William Oughtred built the first slide rule, drawing on Napier’s ideas. That first slide rule was circular, but Oughtred also built the first rectangular one in 1633. The analog devices of Gunter and Oughtred had various advantages and disadvantages compared with digital devices such as the abacus. What is important is that the consequences of these design decisions were being tested in the real world. Calculating Clock A reproduction of Wilhelm Schickard's Calculating Clock. The device could add and subtract six-digit numbers (with a bell for seven-digit overflows) through six interlocking gears, each of which turned one-tenth of a rotation for each full rotation of the gear to its right. Thus, 10 rotations of any gear would produce a “carry” of one digit on the following gear and change the corresponding display. In 1623 the German astronomer and mathematician Wilhelm Schickard built the first calculator. He described it in a letter to his friend the astronomer Johannes Kepler, and in 1624 he wrote again to explain that a machine he had commissioned to be built for Kepler was, apparently along with the prototype, destroyed in a fire. He called it a Calculating Clock, which modern engineers have been able to reproduce from details in his letters. Even general knowledge of the clock had been temporarily lost when Schickard and his entire family perished during the Thirty Years’ War. But Schickard may not have been the true inventor of the calculator. A century earlier, Leonardo da Vinci sketched plans for a calculator that were sufficiently complete and correct for modern engineers to build a calculator on their basis. Arithmetic Machine, or Pascaline The Arithmetic Machine, or Pascaline, a French monetary (nondecimal) calculator designed by Blaise Pascal c. 1642. Numbers could be added by turning the wheels (located along the bottom of the machine) clockwise and subtracted by turning the wheels counterclockwise. Each digit in the answer was displayed in a separate window, visible at the top of the photograph. The first calculator or adding machine to be produced in any quantity and actually used was the Pascaline, or Arithmetic Machine, designed and built by the French mathematician-philosopher Blaise Pascal between 1642 and 1644. It could only do addition and subtraction, with numbers being entered by manipulating its dials. Pascal invented the machine for his father, a tax collector, so it was the first business machine too (if one does not count the abacus). He built 50 of them over the next 10 years. Step Reckoner A reproduction of Gottfried Wilhelm von Leibniz's Step Reckoner, from the original located in the Trinks Brunsviga Museum at Hannover, Germany. Turning the crank (left) rotated several drums, each of which turned a gear connected to a digital counter. In 1671 the German mathematician-philosopher Gottfried Wilhelm von Leibniz designed a calculating machine called the Step Reckoner. (It was first built in 1673.) The Step Reckoner expanded on Pascal’s ideas and did multiplication by repeated addition and shifting. Leibniz was a strong advocate of the binary number system. Binary numbers are ideal for machines because they require only two digits, which can easily be represented by the on and off states of a switch. When computers became electronic, the binary system was particularly appropriate because an electrical circuit is either on or off. This meant that on could represent true, off could represent false, and the flow of current would directly represent the flow of logic. Leibniz was prescient in seeing the appropriateness of the binary system in calculating machines, but his machine did not use it. Instead, the Step Reckoner represented numbers in decimal form, as positions on 10-position dials. Even decimal representation was not a given: in 1668 Samuel Morland invented an adding machine specialized for British money—a decidedly nondecimal system. Pascal’s, Leibniz’s, and Morland’s devices were curiosities, but with the Industrial Revolution of the 18th century came a widespread need to perform repetitive operations efficiently. With other activities being mechanized, why not calculation? In 1820 Charles Xavier Thomas de Colmar of France effectively met this challenge when he built his Arithmometer, the first commercial mass-produced calculating device. It could perform addition, subtraction, multiplication, and, with some more elaborate user involvement, division. Based on Leibniz’s technology, it was extremely popular and sold for 90 years. In contrast to the modern calculator’s credit-card size, the Arithmometer was large enough to cover a desktop. Calculators such as the Arithmometer remained a fascination after 1820, and their potential for commercial use was well understood. Many other mechanical devices built during the 19th century also performed repetitive functions more or less automatically, but few had any application to computing. There was one major exception: the Jacquard loom, invented in 1804–05 by a French weaver, Joseph-Marie Jacquard. Jacquard loomJacquard loom, engraving, 1874. At the top of the machine is a stack of punched cards that would be fed into the loom to control the weaving pattern. This method of automatically issuing machine instructions was employed by computers well into the 20th century.The Jacquard loom was a marvel of the Industrial Revolution. A textile-weaving loom, it could also be called the first practical information-processing device. The loom worked by tugging various-colored threads into patterns by means of an array of rods. By inserting a card punched with holes, an operator could control the motion of the rods and thereby alter the pattern of the weave. Moreover, the loom was equipped with a card-reading device that slipped a new card from a pre-punched deck into place every time the shuttle was thrown, so that complex weaving patterns could be automated. What was extraordinary about the device was that it transferred the design process from a labor-intensive weaving stage to a card-punching stage. Once the cards had been punched and assembled, the design was complete, and the loom implemented the design automatically. The Jacquard loom, therefore, could be said to be programmed for different patterns by these decks of punched cards. For those intent on mechanizing calculations, the Jacquard loom provided important lessons: the sequence of operations that a machine performs could be controlled to make the machine do something quite different; a punched card could be used as a medium for directing the machine; and, most important, a device could be directed to perform different tasks by feeding it instructions in a sort of language—i.e., making the machine programmable. It is not too great a stretch to say that, in the Jacquard loom, programming was invented before the computer. The close relationship between the device and the program became apparent some 20 years later, with Charles Babbage’s invention of the first computer. Technology Computers Ask the Chatbot a Question By the second decade of the 19th century, a number of ideas necessary for the invention of the computer were in the air. First, the potential benefits to science and industry of being able to automate routine calculations were appreciated, as they had not been a century earlier. Specific methods to make automated calculation more practical, such as doing multiplication by adding logarithms or by repeating addition, had been invented, and experience with both analog and digital devices had shown some of the benefits of each approach. The Jacquard loom (as described in the previous section, Computer precursors) had shown the benefits of directing a multipurpose device through coded instructions, and it had demonstrated how punched cards could be used to modify those instructions quickly and flexibly. It was a mathematical genius in England who began to put all these pieces together. Difference EngineThe completed portion of Charles Babbage's Difference Engine, 1832. This advanced calculator was intended to produce logarithm tables used in navigation. The value of numbers was represented by the positions of the toothed wheels marked with decimal numbers.Charles Babbage was an English mathematician and inventor: he invented the cowcatcher, reformed the British postal system, and was a pioneer in the fields of operations research and actuarial science. It was Babbage who first suggested that the weather of years past could be read from tree rings. He also had a lifelong fascination with keys, ciphers, and mechanical dolls. As a founding member of the Royal Astronomical Society, Babbage had seen a clear need to design and build a mechanical device that could automate long, tedious astronomical calculations. He began by writing a letter in 1822 to Sir Humphry Davy, president of the Royal Society, about the possibility of automating the construction of mathematical tables—specifically, logarithm tables for use in navigation. He then wrote a paper, “On the Theoretical Principles of the Machinery for Calculating Tables,” which he read to the society later that year. (It won the Royal Society’s first Gold Medal in 1823.) Tables then in use often contained errors, which could be a life-and-death matter for sailors at sea, and Babbage argued that, by automating the production of the tables, he could assure their accuracy. Having gained support in the society for his Difference Engine, as he called it, Babbage next turned to the British government to fund development, obtaining one of the world’s first government grants for research and technological development. Babbage approached the project very seriously: he hired a master machinist, set up a fireproof workshop, and built a dustproof environment for testing the device. Up until then calculations were rarely carried out to more than 6 digits; Babbage planned to produce 20- or 30-digit results routinely. The Difference Engine was a digital device: it operated on discrete digits rather than smooth quantities, and the digits were decimal (0–9), represented by positions on toothed wheels, rather than the binary digits that Leibniz favored (but did not use). When one of the toothed wheels turned from 9 to 0, it caused the next wheel to advance one position, carrying the digit just as Leibniz’s Step Reckoner calculator had operated. The Difference Engine was more than a simple calculator, however. It mechanized not just a single calculation but a whole series of calculations on a number of variables to solve a complex problem. It went far beyond calculators in other ways as well. Like modern computers, the Difference Engine had storage—that is, a place where data could be held temporarily for later processing—and it was designed to stamp its output into soft metal, which could later be used to produce a printing plate. Nevertheless, the Difference Engine performed only one operation. The operator would set up all of its data registers with the original data, and then the single operation would be repeatedly applied to all of the registers, ultimately producing a solution. Still, in complexity and audacity of design, it dwarfed any calculating device then in existence. The full engine, designed to be room-size, was never built, at least not by Babbage. Although he sporadically received several government grants—governments changed, funding often ran out, and he had to personally bear some of the financial costs—he was working at or near the tolerances of the construction methods of the day, and he ran into numerous construction difficulties. All design and construction ceased in 1833, when Joseph Clement, the machinist responsible for actually building the machine, refused to continue unless he was prepaid. (The completed portion of the Difference Engine is on permanent exhibition at the Science Museum in London.) Charles Babbage: Analytical EngineA portion (completed 1910) of Charles Babbage's Analytical Engine. Only partially built at the time of his death in 1871, this portion contains the “mill” (functionally analogous to a modern computer's central processing unit) and a printing mechanism.While working on the Difference Engine, Babbage began to imagine ways to improve it. Chiefly he thought about generalizing its operation so that it could perform other kinds of calculations. By the time the funding had run out in 1833, he had conceived of something far more revolutionary: a general-purpose computing machine called the Analytical Engine. The Analytical Engine was to be a general-purpose, fully program-controlled, automatic mechanical digital computer. It would be able to perform any calculation set before it. Before Babbage there is no evidence that anyone had ever conceived of such a device, let alone attempted to build one. The machine was designed to consist of four components: the mill, the store, the reader, and the printer. These components are the essential components of every computer today. The mill was the calculating unit, analogous to the central processing unit (CPU) in a modern computer; the store was where data were held prior to processing, exactly analogous to memory and storage in today’s computers; and the reader and printer were the input and output devices. As with the Difference Engine, the project was far more complex than anything theretofore built. The store was to be large enough to hold 1,000 50-digit numbers; this was larger than the storage capacity of any computer built before 1960. The machine was to be steam-driven and run by one attendant. The printing capability was also ambitious, as it had been for the Difference Engine: Babbage wanted to automate the process as much as possible, right up to producing printed tables of numbers. The reader was another new feature of the Analytical Engine. Data (numbers) were to be entered on punched cards, using the card-reading technology of the Jacquard loom. Instructions were also to be entered on cards, another idea taken directly from Jacquard. The use of instruction cards would make it a programmable device and far more flexible than any machine then in existence. Another element of programmability was to be its ability to execute instructions in other than sequential order. It was to have a kind of decision-making ability in its conditional control transfer, also known as conditional branching, whereby it would be able to jump to a different instruction depending on the value of some data. This extremely powerful feature was missing in many of the early computers of the 20th century. By most definitions, the Analytical Engine was a real computer as understood today—or would have been, had not Babbage run into implementation problems again. Actually building his ambitious design was judged infeasible given the current technology, and Babbage’s failure to generate the promised mathematical tables with his Difference Engine had dampened enthusiasm for further government funding. Indeed, it was apparent to the British government that Babbage was more interested in innovation than in constructing tables. All the same, Babbage’s Analytical Engine was something new under the sun. Its most revolutionary feature was the ability to change its operation by changing the instructions on punched cards. Until this breakthrough, all the mechanical aids to calculation were merely calculators or, like the Difference Engine, glorified calculators. The Analytical Engine, although not actually completed, was the first machine that deserved to be called a computer. Ada LovelacePortrait of Ada Lovelace by Margaret Carpenter, 1836.The distinction between calculator and computer, although clear to Babbage, was not apparent to most people in the early 19th century, even to the intellectually adventuresome visitors at Babbage’s soirees—with the exception of a young girl of unusual parentage and education. Augusta Ada King, the countess of Lovelace, was the daughter of the poet Lord Byron and the mathematically inclined Anne Millbanke. One of her tutors was Augustus De Morgan, a famous mathematician and logician. Because Byron was involved in a notorious scandal at the time of her birth, Lovelace’s mother encouraged her mathematical and scientific interests, hoping to suppress any inclination to wildness she may have inherited from her father. Toward that end, Lovelace attended Babbage’s soirees and became fascinated with his Difference Engine. She also corresponded with him, asking pointed questions. It was his plan for the Analytical Engine that truly fired her imagination, however. In 1843, at age 27, she had come to understand it well enough to publish the definitive paper explaining the device and drawing the crucial distinction between this new thing and existing calculators. The Analytical Engine, she argued, went beyond the bounds of arithmetic. Because it operated on general symbols rather than on numbers, it established “a link...between the operations of matter and the abstract mental processes of the most abstract branch of mathematical science.” It was a physical device that was capable of operating in the realm of abstract thought. Lovelace rightly reported that this was not only something no one had built, it was something that no one before had even conceived. She went on to become the world’s only expert on the process of sequencing instructions on the punched cards that the Analytical Engine used; that is, she became the world’s first computer programmer. One feature of the Analytical Engine was its ability to place numbers and instructions temporarily in its store and return them to its mill for processing at an appropriate time. This was accomplished by the proper sequencing of instructions and data in its reader, and the ability to reorder instructions and data gave the machine a flexibility and power that was hard to grasp. The first electronic digital computers of a century later lacked this ability. It was remarkable that a young scholar realized its importance in 1840, and it would be 100 years before anyone would understand it so well again. In the intervening century, attention would be diverted to the calculator and other business machines. computer, Programmable machine that can store, retrieve, and process data. A computer consists of the central processing unit (CPU), main memory (or random-access memory, RAM), and peripherals (e.g., a keyboard, a printer, disc drives). Traditional histories of computers assign generations on the basis of technology. First-generation digital computers, developed during and after World War II, used vacuum tubes and were enormous. The second generation, introduced c. 1960, used transistors and were the first successful commercial computers. Third-generation computers (late 1960s and 1970s) were characterized by miniaturization of components and use of integrated circuits. The microprocessor, introduced in 1974, defines fourth-generation computers. Computers have become all but ubiquitous, in an always evolving variety of forms and types, not least because of the equal ubiquity of the Internet. A computer is a machine that can store and process information. Most computers rely on a binary system, which uses two variables, 0 and 1, to complete tasks such as storing data, calculating algorithms, and displaying information. Computers come in many different shapes and sizes, from handheld smartphones to supercomputers weighing more than 300 tons. computer science, the study of computers and computing, including their theoretical and algorithmic foundations, hardware and software, and their uses for processing information. The discipline of computer science includes the study of algorithms and data structures, computer and network design, modeling data and information processes, and artificial intelligence. Computer science draws some of its foundations from mathematics and engineering and therefore incorporates techniques from areas such as queueing theory, probability and statistics, and electronic circuit design. Computer science also makes heavy use of hypothesis testing and experimentation during the conceptualization, design, measurement, and refinement of new algorithms, information structures, and computer architectures. Computer science is considered as part of a family of five separate yet interrelated disciplines: computer engineering, computer science, information systems, information technology, and software engineering. This family has come to be known collectively as the discipline of computing. These five disciplines are interrelated in the sense that computing is their object of study, but they are separate since each has its own research perspective and curricular focus. (Since 1991 the Association for Computing Machinery [ACM], the IEEE Computer Society [IEEE-CS], and the Association for Information Systems [AIS] have collaborated to develop and update the taxonomy of these five interrelated disciplines and the guidelines that educational institutions worldwide use for their undergraduate, graduate, and research programs.)The major subfields of computer science include the traditional study of computer architecture, programming languages, and software development. However, they also include computational science (the use of algorithmic techniques for modeling scientific data), graphics and visualization, human-computer interaction, databases and information systems, networks, and the social and professional issues that are unique to the practice of computer science. As may be evident, some of these subfields overlap in their activities with other modern fields, such as bioinformatics and computational chemistry. These overlaps are the consequence of a tendency among computer scientists to recognize and act upon their field’s many interdisciplinary connections. Computer science emerged as an independent discipline in the early 1960s, although the electronic digital computer that is the object of its study was invented some two decades earlier. The roots of computer science lie primarily in the related fields of mathematics, electrical engineering, physics, and management information systems. Mathematics is the source of two key concepts in the development of the computer—the idea that all information can be represented as sequences of zeros and ones and the abstract notion of a “stored program.” In the binary number system, numbers are represented by a sequence of the binary digits 0 and 1 in the same way that numbers in the familiar decimal system are represented using the digits 0 through 9. The relative ease with which two states (e.g., high and low voltage) can be realized in electrical and electronic devices led naturally to the binary digit, or bit, becoming the basic unit of data storage and transmission in a computer system. Computers and Technology Quiz Electrical engineering provides the basics of circuit design—namely, the idea that electrical impulses input to a circuit can be combined using Boolean algebra to produce arbitrary outputs. (The Boolean algebra developed in the 19th century supplied a formalism for designing a circuit with binary input values of zeros and ones [false or true, respectively, in the terminology of logic] to yield any desired combination of zeros and ones as output.) The invention of the transistor and the miniaturization of circuits, along with the invention of electronic, magnetic, and optical media for the storage and transmission of information, resulted from advances in electrical engineering and physics. Management information systems, originally called data processing systems, provided early ideas from which various computer science concepts such as sorting, searching, databases, information retrieval, and graphical user interfaces evolved. Large corporations housed computers that stored information that was central to the activities of running a business—payroll, accounting, inventory management, production control, shipping, and receiving. Alan TuringBritish mathematician Alan Turing conceptualized the Turing machine.Theoretical work on computability, which began in the 1930s, provided the needed extension of these advances to the design of whole machines; a milestone was the 1936 specification of the Turing machine (a theoretical computational model that carries out instructions represented as a series of zeros and ones) by the British mathematician Alan Turing and his proof of the model’s computational power. Another breakthrough was the concept of the stored-program computer, usually credited to Hungarian American mathematician John von Neumann. These are the origins of the computer science field that later became known as architecture and organization. In the 1950s, most computer users worked either in scientific research labs or in large corporations. The former group used computers to help them make complex mathematical calculations (e.g., missile trajectories), while the latter group used computers to manage large amounts of corporate data (e.g., payrolls and inventories). Both groups quickly learned that writing programs in the machine language of zeros and ones was not practical or reliable. This discovery led to the development of assembly language in the early 1950s, which allows programmers to use symbols for instructions (e.g., ADD for addition) and variables (e.g., X). Another program, known as an assembler, translated these symbolic programs into an equivalent binary program whose steps the computer could carry out, or “execute.” Other system software elements known as linking loaders were developed to combine pieces of assembled code and load them into the computer’s memory, where they could be executed. The concept of linking separate pieces of code was important, since it allowed “libraries” of programs for carrying out common tasks to be reused. This was a first step in the development of the computer science field called software engineering. Later in the 1950s, assembly language was found to be so cumbersome that the development of high-level languages (closer to natural languages) began to support easier, faster programming. FORTRAN emerged as the main high-level language for scientific programming, while COBOL became the main language for business programming. These languages carried with them the need for different software, called compilers, that translate high-level language programs into machine code. As programming languages became more powerful and abstract, building compilers that create high-quality machine code and that are efficient in terms of execution speed and storage consumption became a challenging computer science problem. The design and implementation of high-level languages is at the heart of the computer science field called programming languages. Increasing use of computers in the early 1960s provided the impetus for the development of the first operating systems, which consisted of system-resident software that automatically handled input and output and the execution of programs called “jobs.” The demand for better computational techniques led to a resurgence of interest in numerical methods and their analysis, an activity that expanded so widely that it became known as computational science. The 1970s and ’80s saw the emergence of powerful computer graphics devices, both for scientific modeling and other visual activities. (Computerized graphical devices were introduced in the early 1950s with the display of crude images on paper plots and cathode-ray tube [CRT] screens.) Expensive hardware and the limited availability of software kept the field from growing until the early 1980s, when the computer memory required for bitmap graphics (in which an image is made up of small rectangular pixels) became more affordable. Bitmap technology, together with high-resolution display screens and the development of graphics standards that make software less machine-dependent, has led to the explosive growth of the field. Support for all these activities evolved into the field of computer science known as graphics and visual computing. Graphical user interfaceThe Xerox Alto was the first computer to use graphical icons and a mouse to control the system—the first graphical user interface (GUI).Closely related to this field is the design and analysis of systems that interact directly with users who are carrying out various computational tasks. These systems came into wide use during the 1980s and ’90s, when line-edited interactions with users were replaced by graphical user interfaces (GUIs). GUI design, which was pioneered by Xerox and was later picked up by Apple (Macintosh) and finally by Microsoft (Windows), is important because it constitutes what people see and do when they interact with a computing device. The design of appropriate user interfaces for all types of users has evolved into the computer science field known as human-computer interaction (HCI). The field of computer architecture and organization has also evolved dramatically since the first stored-program computers were developed in the 1950s. So called time-sharing systems emerged in the 1960s to allow several users to run programs at the same time from different terminals that were hard-wired to the computer. The 1970s saw the development of the first wide-area computer networks (WANs) and protocols for transferring information at high speeds between computers separated by large distances. As these activities evolved, they coalesced into the computer science field called networking and communications. A major accomplishment of this field was the development of the Internet. The idea that instructions, as well as data, could be stored in a computer’s memory was critical to fundamental discoveries about the theoretical behavior of algorithms. That is, questions such as, “What can/cannot be computed?” have been formally addressed using these abstract ideas. These discoveries were the origin of the computer science field known as algorithms and complexity. A key part of this field is the study and application of data structures that are appropriate to different applications. Data structures, along with the development of optimal algorithms for inserting, deleting, and locating data in such structures, are a major concern of computer scientists because they are so heavily used in computer software, most notably in compilers, operating systems, file systems, and search engines. In the 1960s the invention of magnetic disk storage provided rapid access to data located at an arbitrary place on the disk. This invention led not only to more cleverly designed file systems but also to the development of database and information retrieval systems, which later became essential for storing, retrieving, and transmitting large amounts and wide varieties of data across the Internet. This field of computer science is known as information management. Another long-term goal of computer science research is the creation of computing machines and robotic devices that can carry out tasks that are typically thought of as requiring human intelligence. Such tasks include moving, seeing, hearing, speaking, understanding natural language, thinking, and even exhibiting human emotions. The computer science field of intelligent systems, originally known as artificial intelligence (AI), actually predates the first electronic computers in the 1940s, although the term artificial intelligence was not coined until 1956. Three developments in computing in the early part of the 21st century—mobile computing, client-server computing, and computer hacking—contributed to the emergence of three new fields in computer science: platform-based development, parallel and distributed computing, and security and information assurance. Platform-based development is the study of the special needs of mobile devices, their operating systems, and their applications. Parallel and distributed computing concerns the development of architectures and programming languages that support the development of algorithms whose components can run simultaneously and asynchronously (rather than sequentially), in order to make better use of time and space. Security and information assurance deals with the design of computing systems and software that protects the integrity and security of data, as well as the privacy of individuals who are characterized by that data. Finally, a particular concern of computer science throughout its history is the unique societal impact that accompanies computer science research and technological advancements. With the emergence of the Internet in the 1980s, for example, software developers needed to address important issues related to information security, personal privacy, and system reliability. In addition, the question of whether computer software constitutes intellectual property and the related question “Who owns it?” gave rise to a whole new legal area of licensing and licensing standards that applied to software and related artifacts. These concerns and others form the basis of social and professional issues of computer science, and they appear in almost all the other fields identified above. So, to summarize, the discipline of computer science has evolved into the following 15 distinct fields: Algorithms and complexityArchitecture and organizationGraphics and visual computingHuman-computer interactionNetworking and communicationParallel and distributed computingPlatform-based developmentSecurity and information assuranceSocial and professional issues Computer science continues to have strong mathematical and engineering roots. Computer science bachelor’s, master’s, and doctoral degree programs are routinely offered by postsecondary academic institutions, and these programs require students to complete appropriate mathematics and engineering courses, depending on their area of focus. For example, all undergraduate computer science majors must study discrete mathematics (logic, combinatorics, and elementary graph theory). Many programs also require students to complete courses in calculus, statistics, numerical analysis, physics, and principles of engineering early in their studies. A computer is a device for working with information. The information can be numbers, words, pictures, movies, or sounds. Computer information is also called data. Computers can process huge amounts of data very quickly. They also store and display data.People use computers every day at work, at school, and at home. Computers are used in factories to control how things are made and in offices to keep records. People also use computers for sending e-mail, writing reports, shopping, banking, listening to music, and playing games. The Internet, which is a huge network of linked computers, provides information from all over the world. Computers come in many forms. Supercomputers are very powerful and expensive computers that are used for complex work, such as forecasting the weather. Desktop personal computers, or PCs, are used for tasks at the office, at school, and at home. Laptops, notebooks, and tablet computers do the same things as PCs, but they are smaller and easy to carry. Personal digital assistants, or PDAs, are handheld computers. Some very small computers are used to control machines. They are built into such things as airplanes, robots in factories, cars, and even household appliances. A computer system requires both hardware and software. Hardware is the computer’s physical parts. Software is the programs, or instructions, that tell the hardware what to do.All computers have the same basic hardware. The microprocessor is the computer’s “brain.” It is also called the CPU, or central processing unit. The microprocessor handles all the information that goes into and comes out of the computer. The memory is hardware that holds programs and data while the microprocessor uses it.The programs and data are kept permanently on hardware called storage devices. Most computers have a storage device called a hard drive. The hard drive stores data on a metal disk inside the computer. Some storage devices put data on disks that can be easily moved from one computer to another. These disks include CDs and DVDs. They make it easy to share data.Input and output devices are other types of hardware. Input devices let the user enter data or commands into the computer. Input devices include the keyboard and the mouse. Output devices let the user see or hear the results produced by the computer. Output devices include the monitor (or screen), printer, and speakers.Communication, or network, devices connect computers to each other. They let people send data from one computer to another and connect to the Internet. Modems are communication devices that can send data through telephone wires or television cables. Some computers use wireless communication devices. They send data through the air using a small antenna.Computer software is divided into two basic types—the operating system and application software. The operating system controls how the different parts of hardware work together. Application software gives the computer instructions for doing specific tasks, such as word processing or playing games. Most computers are electronic devices. This means that they work with electricity. All computer data is carried in tiny flows of electricity called electric currents. The microprocessor contains thousands or millions of tiny electronic parts called transistors. The transistors act as switches. They control how the electric currents flow.Computers use these electric currents to represent the numbers 0 and 1. Computers use only these two numbers because transistors, like light switches, have only two states—they are either on or off. A transistor that is “on” represents one of the numbers. A transistor that is “off” represents the other. Computers use strings of 0s and 1s to stand for letters, sounds, and all of the other data they handle. For example, a computer stores the word dog as three numbers: 01100100 (d), 01101111 (o), and 01100111 (g).Computers can understand only these patterns of 0s and 1s. All of the instructions that a computer follows have to be in this form. But people find it hard to work with long number patterns. So the people who write computer software, called computer programmers, have their own special languages. These include programming languages called BASIC, Java, and C++. The computer turns programming languages into the number patterns that it can understand.Programmers use these languages to write instructions for the computer. The instructions tell the computer how to process data. The instructions consist of algorithms, which are a series of steps that are used to solve a problem. An English inventor named Charles Babbage designed the first computer in the 1830s. It was mechanical, not electronic, because scientists did not yet know how electricity worked. The design called for more than 50,000 moving parts. The machine was designed to follow instructions that people entered using punched cards. It was so complex that Babbage never got it built. But it is still considered to be the first computer.The first electronic computers were invented in the 1940s. In place of mechanical parts, they used electronic switching devices called vacuum tubes. These computers were so big that just one of them filled a whole room. They cost millions of dollars.Computers improved after the transistor was invented in 1947. The transistor was an electronic switching device that was much smaller and worked better than a vacuum tube. By 1960 transistors had mostly replaced vacuum tubes in computers. The new computers were smaller and more affordable than before.The first computers with microprocessors appeared in the early 1970s. A microprocessor had many tiny transistors on one small wafer, or chip. It made personal computers possible. As more transistors were included in microprocessors, computers became faster and less expensive. Technology Computers What is a personal computer? What are the main components of a personal computer? How does a computer's CPU (Central Processing Unit) work? What is the difference between hardware and software in a computer? How do operating systems like Windows or macOS function on a personal computer? What is the role of RAM (Random Access Memory) in a computer's performance? How does the internet connect to a personal computer? What are common uses for a personal computer in homes and businesses? personal computer (PC), a digital computer designed for use by only one person at a time. A typical personal computer assemblage consists of a central processing unit (CPU), which contains the computer’s arithmetic, logic, and control circuitry on an integrated circuit; two types of computer memory, main memory, such as digital random-access memory (RAM), and auxiliary memory, such as magnetic hard disks and special optical compact discs, or read-only memory (ROM) discs (CD-ROMs and DVD-ROMs); and various peripheral devices, including a display screen, keyboard and mouse, and printer. See also computer: History of computing. Computers small and inexpensive enough to be purchased by individuals for use in their homes first became feasible in the 1970s, when large-scale integration made it possible to construct a sufficiently powerful microprocessor on a single semiconductor chip. A small firm named MITS made the first personal computer, the Altair. This computer, which used Intel Corporation’s 8080 microprocessor, was developed in 1974. Though the Altair was popular among computer hobbyists, its commercial appeal was limited. The personal computer industry truly began in 1977, with the introduction of three preassembled mass-produced personal computers: the Apple Computer, Inc. (now Apple Inc.), Apple II, the Tandy Radio Shack TRS-80, and the Commodore Business Machines Personal Electronic Transactor (PET). These machines used eight-bit microprocessors (which process information in groups of eight bits, or binary digits, at a time) and possessed rather limited memory capacity—i.e., the ability to address a given quantity of data held in memory storage. But because personal computers were much less expensive than mainframe computers (the bigger computers typically deployed by large business, industry, and government organizations), they could be purchased by individuals, small and medium-sized businesses, and primary and secondary schools. Of these computers, the TRS-80 dominated the market. The TRS-80 microcomputer came with four kilobytes of memory, a Z80 microprocessor, a BASIC programming language, and cassettes for data storage. To cut costs, the machine was built without the ability to type lowercase letters. Thanks to Tandy’s chain of Radio Shack stores and the breakthrough price ($399 fully assembled and tested), the machine was successful enough to persuade the company to introduce a more powerful computer two years later, the TRS-80 Model II, which could reasonably be marketed as a small-business computer. The Apple II received a great boost in popularity when it became the host machine for VisiCalc, the first electronic spreadsheet (computerized accounting program). Other types of application software soon developed for personal computers. Electronics & Gadgets Quiz IBM Personal ComputerThe IBM Personal Computer (PC) was introduced in 1981. Microsoft supplied the machine's operating system, MS-DOS (Microsoft Disk Operating System).IBM Corporation, the world’s dominant computer maker, did not enter the new market until 1981, when it introduced the IBM Personal Computer, or IBM PC. The IBM PC was significantly faster than rival machines, had about 10 times their memory capacity, and was backed by IBM’s large sales organization. The IBM PC was also the host machine for 1-2-3, an extremely popular spreadsheet introduced by the Lotus Development Corporation in 1982. The IBM PC became the world’s most popular personal computer, and both its microprocessor, the Intel 8088, and its operating system, which was adapted from Microsoft Corporation’s MS-DOS system, became industry standards. Rival machines that used Intel microprocessors and MS-DOS became known as “IBM compatibles” if they tried to compete with IBM on the basis of additional computing power or memory and “IBM clones” if they competed simply on the basis of low price. In 1983 Apple introduced Lisa, a personal computer with a graphical user interface (GUI) to perform routine operations. A GUI is a display format that allows the user to select commands, call up files, start programs, and do other routine tasks by using a device called a mouse to point to pictorial symbols (icons) or lists of menu choices on the screen. This type of format had certain advantages over interfaces in which the user typed text- or character-based commands on a keyboard to perform routine tasks. A GUI’s windows, pull-down menus, dialog boxes, and other controlling mechanisms could be used in new programs and applications in a standardized way, so that common tasks were always performed in the same manner. The Lisa’s GUI became the basis of Apple’s Macintosh personal computer, which was introduced in 1984 and proved extremely successful. The Macintosh was particularly useful for desktop publishing because it could lay out text and graphics on the display screen as they would appear on the printed page. The Macintosh’s graphical interface style was widely adapted by other manufacturers of personal computers and PC software. In 1985 the Microsoft Corporation introduced Microsoft Windows, a graphical user interface that gave MS-DOS-based computers many of the same capabilities of the Macintosh. Windows became the dominant operating environment for personal computers. Technology Computers Ask the Chatbot a Question computer, device for processing, storing, and displaying information.Computer once meant a person who did computations, but now the term almost universally refers to automated electronic machinery. The first section of this article focuses on modern digital electronic computers and their design, constituent parts, and applications. The second section covers the history of computing. For details on computer architecture, software, and theory, see computer science. The first computers were used primarily for numerical calculations. However, as any information can be numerically encoded, people soon realized that computers are capable of general-purpose information processing. Their capacity to handle large amounts of data has extended the range and accuracy of weather forecasting. Their speed has allowed them to make decisions about routing telephone connections through a network and to control mechanical systems such as automobiles, nuclear reactors, and robotic surgical tools. They are also cheap enough to be embedded in everyday appliances and to make clothes dryers and rice cookers “smart.” Computers have allowed us to pose and answer questions that were difficult to pursue in the past. These questions might be about DNA sequences in genes, patterns of activity in a consumer market, or all the uses of a word in texts that have been stored in a database. Increasingly, computers can also learn and adapt as they operate by using processes such as machine learning. Computers also have limitations, some of which are theoretical. For example, there are undecidable propositions whose truth cannot be determined within a given set of rules, such as the logical structure of a computer. Because no universal algorithmic method can exist to identify such propositions, a computer asked to obtain the truth of such a proposition will (unless forcibly interrupted) continue indefinitely—a condition known as the “halting problem.” (See Turing machine.) Other limitations reflect current technology. For example, although computers have progressed greatly in terms of processing data and using artificial intelligence algorithms, they are limited by their incapacity to think in a more holistic fashion. Computers may imitate humans—quite effectively, even—but imitation may not replace the human element in social interaction. Ethical concerns also limit computers, because computers rely on data, rather than a moral compass or human conscience, to make decisions. A Brief History of the Computer Told from the 1990s: A Quiz Analog computers use continuous physical magnitudes to represent quantitative information. At first they represented quantities with mechanical components (see differential analyzer and integrator), but after World War II voltages were used; by the 1960s digital computers had largely replaced them. Nonetheless, analog computers, and some hybrid digital-analog systems, continued in use through the 1960s in tasks such as aircraft and spaceflight simulation. One advantage of analog computation is that it may be relatively simple to design and build an analog computer to solve a single problem. Another advantage is that analog computers can frequently represent and solve a problem in “real time”; that is, the computation proceeds at the same rate as the system being modeled by it. Their main disadvantages are that analog representations are limited in precision—typically a few decimal places but fewer in complex mechanisms—and general-purpose devices are expensive and not easily programmed. In contrast to analog computers, digital computers represent information in discrete form, generally as sequences of 0s and 1s (binary digits, or bits). The modern era of digital computers began in the late 1930s and early 1940s in the United States, Britain, and Germany. The first devices used switches operated by electromagnets (relays). Their programs were stored on punched paper tape or cards, and they had limited internal data storage. For historical developments, see the section Invention of the modern computer. During the 1950s and ’60s, Unisys (maker of the UNIVAC computer), International Business Machines Corporation (IBM), and other companies made large, expensive computers of increasing power. They were used by major corporations and government research laboratories, typically as the sole computer in the organization. In 1959 the IBM 1401 computer rented for $8,000 per month (early IBM machines were almost always leased rather than sold), and in 1964 the largest IBM S/360 computer cost several million dollars. These computers came to be called mainframes, though the term did not become common until smaller computers were built. Mainframe computers were characterized by having (for their time) large storage facilities, fast components, and powerful computational abilities. They were highly reliable, and, because they frequently served vital needs in an organization, they were sometimes designed with redundant components that let them survive partial failures. Because they were complex systems, they were operated by a staff of systems programmers, who alone had access to the computer. Other users submitted “batch jobs” to be run one at a time on the mainframe. Such systems remain important today, though they are no longer the sole, or even primary, central computing resource of an organization, which will typically have hundreds or thousands of personal computers (PCs). Mainframes now provide high-capacity data storage for Internet servers, or, through time-sharing techniques, they allow hundreds or thousands of users to run programs simultaneously. Because of their current roles, these computers are now called servers rather than mainframes.

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