

MACHINES TO DO ARITHMETIC

The term *computer* dates back to the 1600s. However, until the 1950s, the term referred almost exclusively to a *human* who performed computations.

For human beings, the task of performing large amounts of computation is one that is laborious, time consuming, and error prone. Thus, the human desire to mechanize arithmetic is an ancient one. One of the earliest “personal calculators” was the **abacus**, with movable beads strung on rods to count and to do calculations. Although its exact origin is unknown, the abacus was used by the Chinese perhaps 3000 to 4000 years ago and is still used today throughout Asia. Early merchants used the abacus in trading transactions.

The ancient British stone monument **Stonehenge**, located near Salisbury, England, was built between 1900 and 1600 B.C. and, evidently, was used to predict the changes of the seasons.

In the twelfth century, a Persian teacher of mathematics in Baghdad, Muhammad ibn-Musa al-Khowarizm, developed some of the first step-by-step procedures for doing computations. The word **algorithm** used for such procedures is derived from his name.

In Western Europe, the Scottish mathematician John Napier (1550–1617) designed a set of ivory rods (called **Napier’s bones**) to assist with doing multiplications. Napier also developed tables of logarithms and other multiplication machines.

The videotape series entitled “The Machine That Changed The World” is highly recommended by the authors. For information about it, see <http://ei.cs.vt.edu/~history/TMTCTW.html>. A Jacquard Loom, Hollerith’s tabulator, the ENIAC, UNIVAC, early chips, and other computer artifacts can also be viewed at the National Museum of American History of the Smithsonian Institution in Washington, D.C. Also see this book’s Web site for more information about the history of computing.

EARLY CALCULATORS

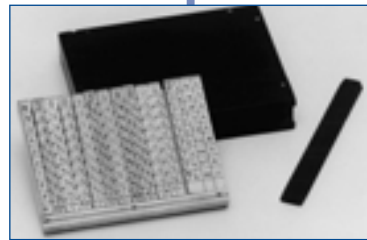


3000 B.C. ABACUS

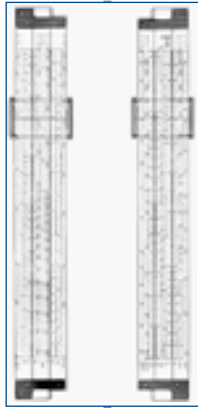


1900-1600 B.C. STONEHENGE

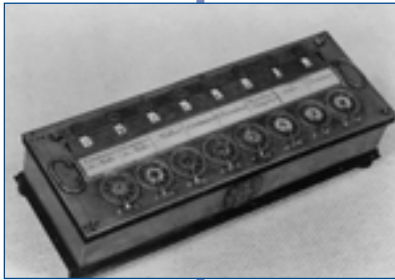
12TH CENTURY: AL-KHOWARIZM



1612 NAPIER'S BONES



1630 SLIDE RULE



1642 PASCALINE



1673 LEIBNIZ' CALCULATOR

The English mathematician William Oughtred invented a circular **slide rule** in the early 1600s. Slide rules were based on Napier's logarithms, and more modern ones like that shown here were used by engineers and scientists through the 1950s and into the 1960s to do rapid approximate computations.

The young French mathematician **Blaise Pascal** (1623–1662) invented one of the first mechanical adding machines to help his father with calculating taxes. It used a series of eight ten-toothed wheels (one tooth for each decimal digit), which were connected so that numbers could be added or subtracted by moving the wheels.

The "Pascaline" was a **digital** calculator, because it represented numerical information as discrete digits, as opposed to a graduated scale like that used in *analog* instruments of measurement such as nondigital clocks and thermometers. Each digit was represented by a gear that had ten different positions (a *ten-state device*) so that it could "count" from 0 through 9 and, upon reaching 10, would reset to 0 and advance the gear in the next column so as to represent the action of "carrying" to the next digit.

Although Pascal built more than 50 of his adding machines, his commercial venture failed because the devices could not be built with sufficient precision for practical use.

The German mathematician **Gottfried Wilhelm von Leibniz** invented an improved mechanical calculator that, like the Pascaline, used a system of gears and dials to do calculations. However, it was more reliable and accurate than the Pascaline and could perform all four of the basic arithmetic operations of addition, subtraction, multiplication, and division.

A number of other mechanical calculators followed that further refined Pascal's and Leibniz's designs, and by the end of the nineteenth century, these calculators had become important tools in science, business, and commerce.

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THE STORED PROGRAM

The fundamental idea that distinguishes computers from calculators is the concept of a stored **program** that controls the computation. A program is a sequence of instructions that the computer follows to solve some problem. An income tax form is a good analogy. While a calculator can be a useful tool in the process, computing taxes involves much more than arithmetic. To produce the correct result, one must execute the form's precise sequence of steps of writing numbers down (storage), looking numbers up (retrieval), and computation to produce the correct result. Likewise, a computer program is a precise sequence of steps designed to accomplish some human task.

The stored program concept also gives the computer its amazing versatility. Unlike most other machines, which are engineered to mechanize a single task, a computer can be programmed to perform many different tasks—that is, the choice of task is deferred to the user. This is the fascinating paradox of the computer: Although its **hardware** is designed for a very specific task—the mechanization of arithmetic—computer software programs enable the computer to perform a dizzying array of human tasks, from navigational control of the space shuttle to word processing to musical composition. For this reason, the computer is sometimes called the **universal machine**.

An early example of a stored program automatically controlling a hardware device can be found in the weaving loom invented in 1801 by the Frenchman **Joseph Marie Jacquard**. Holes punched in metal cards directed the action of this loom: A hole punched in one of the cards would enable its corresponding thread to come through and be incorporated into the weave at a given point in the process; the absence of a hole would exclude an undesired thread. To change to a different weaving pattern, the operator of this loom would simply switch to another set of cards. Jacquard's loom is thus one of the first examples of a programmable machine, and many later computers would make similar use of punched cards.

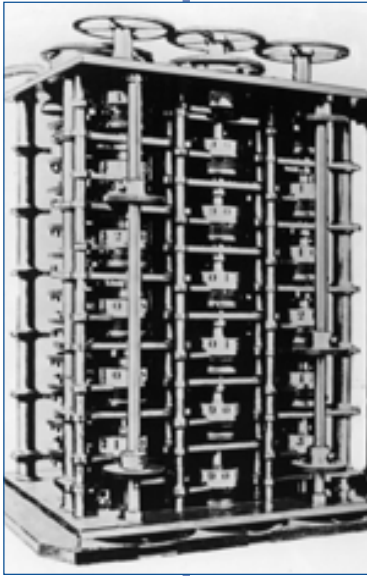
The punched card's present-or-absent hole also marks the early occurrence of another key concept in the history of computing—the **two-state device**, which refers to any mechanism for which there are only two possible conditions. Within a decade, thousands of automated looms were being used in Europe, threatening the traditional weaver's way of life. In protest, English weavers who called themselves *Luddites* rioted and destroyed several of the new looms and cards. Some of the Luddites were hanged for their actions. (The term Luddite is still used today to refer to someone who is skeptical of new technology.)



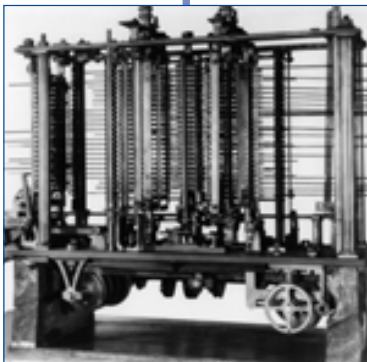
1801 JACQUARD LOOM

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MECHANICAL COMPUTERS



1822 BABBAGE'S DIFFERENCE ENGINE



1833 BABBAGE'S ANALYTICAL ENGINE

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The two fundamental concepts of mechanized calculation and stored program control were combined by the English mathematician **Charles Babbage** (1792–1871). In Babbage's lifetime, humans involved in almost any form of computation relied heavily upon books of mathematical tables that contained the results of calculations that had already been performed by others. However, such mathematical tables took far too long for humans to produce and were typically rife with errors. Moreover, world travel, the Industrial Revolution, and other new scientific and economic realities had produced an explosion in the need for mathematical computations. It was clear to Babbage that "human computers" were simply not up to the task of supplying the demand.

In 1822, supported by the British government, Babbage began work on a machine that he called the **Difference Engine**. Comprised of a system of gears, the Difference Engine was designed to compute polynomials for preparing mathematical tables. Babbage continued this work until 1833, when he abandoned this effort having completed only part of the machine. According to Doron Swade, curator of the London Science Museum, the cantankerous Babbage argued with his engineer, ran out of money, and was beset by personal rivalry.

In 1833, Babbage began the design of a much more sophisticated machine that he called his **Analytical Engine**, which was to have over 50,000 components. The operation of this machine was to be far more versatile and fully automatic, controlled by programs stored on punched cards, an idea based on Jacquard's earlier work. In fact, as Babbage himself observed: "The analogy of the Analytical Engine with this well-known process is nearly perfect."

The basic design of Babbage's Analytical Engine corresponded remarkably to that of modern computers in that it involved the four primary operations of a computer system: **processing, storage, input, and output**. It included a mill for carrying out the arithmetic computations according to a sequence of instructions (like the central processing unit in modern machines); the store was the machine's memory for storing up to 1,000 50-digit numbers and intermediate results; input was to be by means of punched cards; output was to be printed; and other components were designed for the transfer of information between components. When completed, it would have been as large as a locomotive, been powered by steam, and able to calculate to six decimal places of accuracy very rapidly and print out results, all of which was to be controlled by a stored program!

Babbage's machine was not built during his lifetime, but it is nevertheless an important part of the history of computing because many of the concepts of its design are used in modern computers. For this reason, Babbage is sometimes called the "Father of Computing."

Ada Augusta, Lord Byron's daughter, was one of the few people other than Babbage who understood the Analytical Engine's design. This enabled her to develop "programs" for the machine, and for this reason she is sometimes called "the first programmer." She described the similarity of Jacquard's and Babbage's inventions: "The Analytical Engine weaves algebraic patterns just as the Jacquard loom weaves flowers and leaves." In the 1980s, the programming language Ada was named in her honor.



1842 ADA AUGUSTA

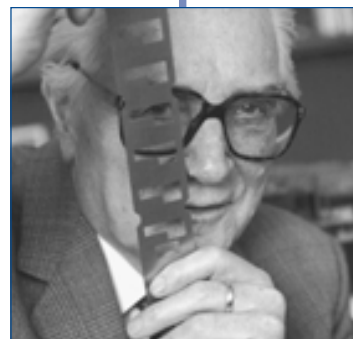
During the next 100 years, little progress was made in realizing Babbage's dream. About the only noteworthy event during this time was the invention by **Herman Hollerith** of an electric tabulating machine that could tally census statistics that had been stored on punched cards. There was a fear that, because of growing population, it would not be possible to complete processing of the 1890 census before the next one was to be taken. Hollerith's machine enabled the United States Census Bureau to complete the 1890 census in 2 1/2 years. The Hollerith Tabulating Company later merged with other companies to form the International Business Machines (IBM) Corporation.

ELECTROMECHANICAL COMPUTERS



1890 HOLLERITH'S TABULATING MACHINE

Much of Babbage's dream was finally realized in the "Z" series of computers developed by the young German engineer **Konrad Zuse** in the 1930s. Ingeniously, Zuse designed his computers to mechanize arithmetic of **binary** numbers rather than that of decimal numbers. Because there are only two binary digits, 0 and 1, Zuse could construct his machine from two-state devices instead of ten-state devices, thus greatly simplifying the engineering of his computer. The two-state device Zuse deployed was the electromechanical relay, a two-position switch that would either complete or break the circuit connecting two phone lines. This mechanism was in wide use in the telephone industry to automate connections previously managed by human operators.



1935-1938 KONRAD ZUSE

However, Zuse ultimately grew dissatisfied with the slow speed at which the relay switched from one state to the other. His assistant, **Helmut Schreyer**, made the brilliant suggestion of using vacuum tubes, which could switch between states—on and off—electronically, thousands of times faster than any mechanical device involving moving parts. In the middle of World War II, however, Adolf Hitler was convinced that victory was near and refused to fund Zuse's proposal to build the first fully **electronic** computer.

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1937 ALAN TURING



1944 MARK I

EARLY ELECTRONIC COMPUTERS



1936-1939 ATANASOFF'S
ELECTRONIC DIGITAL
COMPUTER (ABC)

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In addition to building electromechanical computers, Konrad Zuse in 1945 designed a high-level programming language that he named Plankalkül. Although Zuse wrote programs using this language, it was never actually implemented due to a lack of funding. As a result, it lay in obscurity until 1972 when Zuse's manuscripts were discovered. This language was amazingly sophisticated for its time—over 15 years passed before its features began to appear in other languages. Zuse designed programs to perform tasks as diverse as integer and floating-point arithmetic, sorting lists of numbers, and playing chess.

World War II also spurred the development of computing devices in the United States, Britain, and Europe. In Britain, **Alan Turing** developed the universal machine concept, forming the basis of **computability theory**. (See Chapter 4.) During World War II, he was part of a team whose task was to decrypt intercepted messages of the German forces. Several machines resulted from this British war effort, one of which was the Collosus, finished in 1943.

The best-known computer built before 1945 was the Harvard **Mark I** (whose full name was the Harvard-IBM Automatic Sequence Controlled Calculator). Like Zuse's "Z" machines, it was driven by electromechanical relay technology. Repeating much of the work of Babbage, Howard Aiken and others at IBM constructed this large, automatic, general-purpose, electromechanical calculator. It was sponsored by the U.S. Navy and (like Babbage's machines) was intended to compute mathematical and navigational tables.

The first fully electronic binary computer, the **ABC** (Atanasoff-Berry Computer), was developed by John **Atanasoff** and **Clifford Berry** at Iowa State University during 1937-1942. It introduced the ideas of binary arithmetic, regenerative memory, and logic circuits.

Unfortunately, because the ABC was never patented and because others failed at the time to see its utility, it took three decades before Atanasoff and Berry received recognition for this remarkable technology. Although the ENIAC (1943-1946) bore the title of the first fully electronic computer for many years, a historic 1973 court decision ruled that Atanasoff was the legal inventor of the first electronic digital computer.

Grace Murray Hopper (1907–1992) began work as a coder—what we today would call a programmer—for the Mark I in 1944. In the late 1950s, “Grandma COBOL,” as she has affectionately been called, led the effort to develop the COBOL programming language for business applications.

The actual physical components that make up a computer system are its **hardware**. Several generations of computers can be identified by their type of hardware. **First-generation** computers are characterized by their extensive use of vacuum tubes. Although they could do calculations much more rapidly than mechanical and electromechanical computers, the heat generated by large numbers of vacuum tubes and their short lifetimes led to frequent failures.

The ENIAC (Electronic Numerical Integrator and Computer) is arguably the best known of the early electronic computers (and long thought to be the first). It was designed by **J. Presper Eckert** and **John Mauchly**, who began work on it in 1943 at the Moore School of Engineering at the University of Pennsylvania. When it was completed in 1946, this 30-ton machine had 18,000 vacuum tubes, 70,000 resistors, and 5 million soldered joints and consumed 160 kilowatts of electrical power. Stories are told of how the lights in Philadelphia dimmed when the ENIAC was operating.

This extremely large machine could multiply numbers approximately 1000 times faster than the Mark I, but it was quite limited in its applications and was used primarily by the Army Ordnance Department to calculate firing tables and trajectories for various types of artillery shells. The instructions that controlled the ENIAC’s operation were entered into the machine by rewiring some of the computer’s circuits. This complicated process was very time consuming, sometimes taking a number of people several days; during this time, the computer was idle. In other early computers, the instructions were stored outside the machine on punched cards or some other medium and were transferred into the machine one at a time for interpretation and execution. Unfortunately, because of the relative slowness of the moving parts of mechanical input devices in comparison to the electronic parts of the computer dedicated to processing, such computers would always finish executing the instruction long before the next instruction was finished loading. Thus, again, the processing portion of the computer was sitting idle too much of the time.



1944 GRACE HOPPER

FIRST-GENERATION COMPUTERS



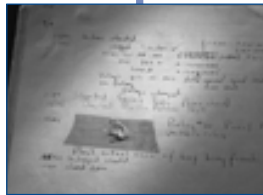
1945-1956 FIRST-GENERATION COMPUTERS—VACUUM TUBES



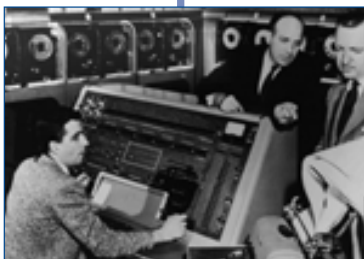
1943-1946 ENIAC

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1945 JOHN VON NEUMANN'S
"FIRST DRAFT OF A
REPORT ON THE EDVAC"



1945 COMPUTER BUG



1951 UNIVAC

In 1945, John von Neumann wrote "First Draft of a Report on the EDVAC (Electronic Discrete Variable Automatic Computer)" computer in which he described a scheme that required program instructions to be stored internally before execution. This led to his being credited as the inventor of the stored-program concept. The architectural design he described is still known as the **von Neumann architecture** (although there is evidence that others including Eckert and Mauchly and Zuse had similar ideas several years before this).

The advantage of executing instructions from a computer's memory rather than directly from a mechanical input device is that it eliminates time that the computer must spend waiting for instructions. Instructions can be processed more rapidly and more importantly; they can be modified by the computer itself while computations are taking place. The introduction of this scheme to computer **architecture** was crucial to the development of general-purpose computers.

While working on the Mark II computer, Grace Hopper found one of the first computer "**bugs**"—an actual bug stuck in one of the thousands of relays that has been preserved in the National Museum of American History of the Smithsonian Institution. She glued it into the logbook, and subsequent efforts to find the cause of machine stoppage were reported to Aiken as "debugging the computer."

Eckert and Mauchly left the University of Pennsylvania to form the Eckert–Mauchly Computer Corporation, which built the UNIVAC (Universal Automatic Computer). Started in 1946 and completed in 1951, it was the first commercially available computer designed for both scientific and business applications. The UNIVAC achieved instant fame partly due to its correct (albeit unbelievably) prediction on national television of the election of President Eisenhower in the 1952 U.S. presidential election, based upon 5% of the returns. UNIVAC soon became the common name for computers.

Soon afterward, because of various setbacks, Eckert and Mauchly sold their company to the Remington–Rand Corporation, who sold the first UNIVAC to the Census Bureau in 1951.

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Second-generation computers, built between 1956 and 1963, used **transistors** in place of the large, cumbersome vacuum tubes, marking the beginning of the great computer shrinkage. These computers were smaller, faster, required less power, generated far less heat, and were more reliable than their predecessors. They were also less expensive.

Early computers were difficult to use because of the complex coding schemes used to represent programs and data. A key development during the late 1950s and early 1960s was the development of programming languages that made it much easier to develop programs.

In 1957, after three years of work, John Backus and his colleagues delivered the first **FORTRAN** (FORmula TRANslation) compiler for the IBM 704. Their first report commented that a programmer was able to write and debug in four to five hours a program that would have taken several days to complete before. FORTRAN has undergone several revisions and remains a powerful language for scientific computing.

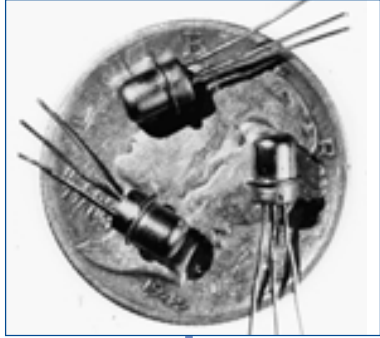
In 1958, IBM introduced the first of the second-generation computers (the 7090 and other computers in their 7000 series), vaulting IBM from computer obscurity to first place in the computer industry.

Also in 1958, as part of his work in developing artificial intelligence, John McCarthy developed the programming language **LISP** (LISt Processing) for manipulating strings of symbols, a non-numeric processing language.

Since 1952, Grace Hopper had been developing a series of natural-language-like programming languages for use in business data processing. This culminated in 1960 with the development of **COBOL** (COmmon Business Oriented Language) by an industry-wide team. Since then, more programs have been written in COBOL than in any other programming language.

Another language that appeared in 1960 was **ALGOL 60** (ALGOrithmic Language), which became the basis of many programming languages that followed, such as **Pascal**.

SECOND-GENERATION COMPUTERS



1956–1963 SECOND GENERATION COMPUTERS—EARLY TRANSISTORS

1957 FORTRAN

1958 IBM 7090

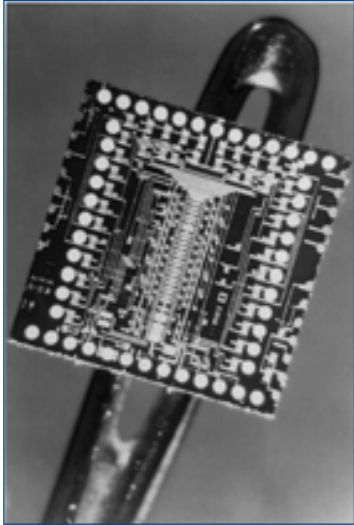
LISP

1960 COBOL

ALGOL 60

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THIRD-GENERATION COMPUTERS



Third-generation computers used **integrated circuits** (IC, chips), which first became commercially available from the Fairchild Corporation. These ICs were based on the pioneering work of **Jack Kilby** and **Robert Noyce**.

It was also during this period that, in addition to improved hardware, computer manufacturers began to develop collections of programs known as **system software**, which made computers easier to use. One of the more important advances in this area was the third-generation development of **operating systems**. Two important early operating systems still used today are Unix (1971) and MS-DOS (1981).

1964-1971 THIRD-GENERATION COMPUTERS—CHIPS AND INTEGRATED CIRCUITS



The **IBM System/360**, introduced in 1964, is commonly accepted as the first of the third generation of computers. Orders for this family of mutually compatible computers and peripherals climbed to 1000 per month within two years

1964 THE IBM SYSTEM/360



In 1965, Digital Equipment Corporation introduced the **PDP-8**, the first commercially successful **minicomputer**. Because of its speed, small size, and reasonable cost— \$18,000, less than 20% of the six-digit price tag for an IBM 360 mainframe—it became a popular computer in many scientific establishments, small businesses, and manufacturing plants.

1965 PDP-8

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In 1968, **Douglas Engelbart** and his research team worked at developing a more user-friendly form of computing, usable by average persons and for purposes other than numerical computation. Engelbart's inventions anticipated many of the attributes of personal computing, including the **mouse**, word processor, windowed interfaces, integrated "Help," and linked text that would later be termed "hypertext."

Disillusioned by how work on the multiuser operating system Multics was proceeding, **Ken Thompson** of Bell Telephone Laboratories began work in 1969 on a simpler OS aimed at the single user. His first implementation of Unix was written in the assembly language of a spare Digital Equipment Corporation PDP-7 computer. In a pun on the name Multics, the new operating system was named Unix.

Unix is still undergoing development today and has become one of the most popular operating systems. It is the only operating system that has been implemented on computers ranging from microcomputers to supercomputers.

Another noteworthy event began in 1969 when the Advanced Research Projects Agency (ARPA) of the U.S. Department of Defense introduced the **ARPANET**, a network linking computers at some of the department's university research centers. Transmissions between the ARPANET computers traveled in the form of **packets**, each of which was addressed so that it could be routed to its destination. As more and more hosts were added to the ARPANET backbone, it became known as the **Internet**.

**1968 DOUGLAS ENGELBART:
COMPUTER MOUSE,
TWO-DIMENSIONAL DISPLAY,
EDITING, HYPERMEDIA**

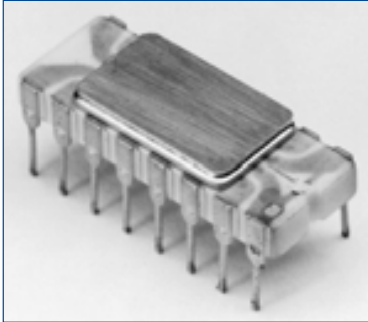


1969 KEN THOMPSON: UNIX

**ARPANET—
THE BEGINNING OF
THE INTERNET**

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FOURTH-GENERATION COMPUTERS



1971 INTEL 4004 CHIP



1973 DENNIS RITCHIE: C

ETHERNET

HISTORIC COURT DECISION
REGARDING FIRST ELECTRONIC
COMPUTER

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Computers from the 1980s on, commonly called **fourth-generation computers**, use very large-scale integrated (VLSI) circuits on silicon chips and other microelectronic advances to shrink their size and cost still more while enlarging their capabilities. A typical chip is equivalent to millions of transistors, is smaller than a baby's fingernail, weighs a small fraction of an ounce, requires only a trickle of power, and costs but a few dollars.

The first chip was the 4004 chip designed by Intel's **Ted Hoff**, giving birth to the microprocessor, which marked the beginning of the fourth generation of computers. This, along with the first use of an 8-inch floppy disk at IBM, ushered in the era of the personal computer.

Robert Noyce, one of the cofounders of the Intel Corporation (which introduced the 4004 microprocessor in 1971), contrasted microcomputers with the ENIAC as follows:

An individual integrated circuit on a chip perhaps a quarter of an inch square now can embrace more electronic elements than the most complex piece of electronic equipment that could be built in 1950. Today's microcomputer, at a cost of perhaps \$300, has more computing capacity than the first electronic computer, ENIAC. It is twenty times faster, has a larger memory, consumes the power of a light bulb rather than that of a locomotive, occupies 1/30,000 the volume and costs 1/10,000 as much. It is available by mail order or at your local hobby shop.

To simplify the task of transferring the Unix operating system to other computers, Ken Thompson began to search for a high-level language in which to rewrite Unix. None of the languages in existence at the time were appropriate; therefore, in 1970, Thompson began designing a new language called B. By 1972, it had become apparent that B was not adequate for implementing Unix. At that time, **Dennis Ritchie**, also at Bell Labs, designed a successor language to B that he called C, and approximately 90 percent of Unix was rewritten in C.

Other noteworthy events in 1973 included the following:

- **Ethernet**, the basis for LANs (Local Area Networks), was developed at Xerox PARC by Robert Metcalf
- A district court in Minneapolis ruled that John Atanasoff was the legal inventor of the first electronic digital computer, thus invalidating Eckert's and Mauchly's patent.

Noteworthy in 1974:

- The MITS **Altair 8800** hobby-kit computer was invented by Edward Roberts (who coined the term **personal computer**), William Yates, and Jim Bybee. It was driven by the 8-bit Intel **8080** chip, had 256 bytes of memory, but no keyboard, no display, and no external storage. It sold for \$300–400.

- **Bill Gates** and **Paul Allen** wrote a BASIC compiler for the Altair.

- Working in a garage, **Steven Jobs** and **Steve Wozniak** developed the **Apple I**.

One of the most popular early personal computers was the **Apple II**, introduced in 1976 by **Steven Jobs** and **Steve Wozniak**. Because of its affordability and the availability of basic software applications, it was an immediate success, especially in schools and colleges.

The first **supercomputer** and the fastest machine of its day, the **Cray I**, developed by **Seymour Cray**, was also introduced in 1976. It was built in the shape of a C so components would be close together, reducing the time for electronic signals to travel between them.

Also in 1976, **Apple Corporation** and **Microsoft Corporation** were founded.

1974

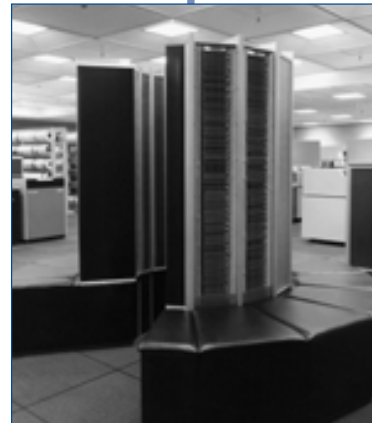
ALTAIR

BASIC

JOBS & WOZNIAK: APPLE 1



1976 APPLE II



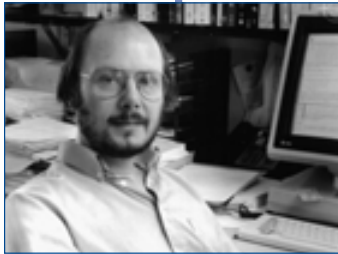
CRAY 1

APPLE CORP.
MICROSOFT CORP.

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1981 IBM PC



1983 BJARNE STROUSTRUP: C++

NOVELL
ANNOUNCES NETWORK

TCP/IP

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In 1981, IBM entered the personal computer market with the IBM PC, originally called the Acorn. Driven by the Intel 8-bit 8088 chip, it used Microsoft's **DOS** operating system under an agreement that gave Microsoft all the profits in exchange for their having borne the development costs. MS-DOS thus became the most popular operating system for personal computers, and the PC established a microcomputer standard adopted by many other manufacturers of personal computers.

The IBM XT debuted the following year, sporting a 10-megabyte hard disk drive. The IBM AT followed in 1983, driven by the 16-bit Intel 80286 microprocessor, the first in the line of Intel's "80x86" chips.

By the late 1970s, a new approach to programming appeared on the scene—**object-oriented programming** (OOP)—that emphasized the modeling of objects through classes and inheritance. A research group at Xerox' Palo Alto Research Center (PARC) created the first truly object-oriented language, named **Smalltalk-80**.

Another Bell Labs researcher, **Bjarne Stroustrup**, began the work of extending C with object-oriented features. In 1983, the redesigned and extended programming language C With Classes was introduced with the new name **C++**.

Also in 1983

- **Novell Data Systems** introduced NetWare, a network operating system (NOS), which made possible the construction of a **Local Area Network (LAN)** of IBM PC-compatible microcomputers.

- **Transmission Control Protocol/Internet Protocol (TCP/IP)** became the official protocol governing transmitting and receiving of data via the ARPANET. Later that year, the University of California at Berkeley released a new version of BSD (also known as Berkeley UNIX), which included TCP/IP, thus providing academic computing systems nationwide with the technology to tie into the ARPANET. Explosive growth in the ARPANET resulted.

Using a renowned Orwellian advertisement parodying the downtrodden masses subservient to the IBM PC, Apple announced in 1984 the **Macintosh**, a new personal computer driven by the 32-bit Motorola 68000 microprocessor. Inspired by Steve Jobs' visit to Xerox PARC in 1979, the "Mac" brought the graphical user interface (GUI) to personal computing.

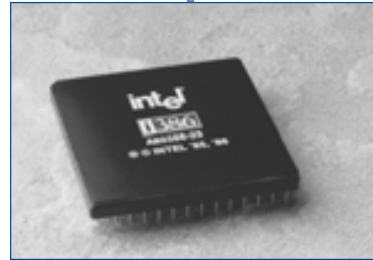


1984 MACINTOSH

In 1985, Microsoft introduced **Windows 1.0**, its graphical user interface for IBM-PC compatibles. It was not until the release of Windows 3.0 in 1990, however, that it gained widespread acceptance.

1985 WINDOWS

In 1986, **Intel** released the 32-bit **80386 chip** (better known as the "386" chip), which became the best-selling microprocessor in history. It contained 275,000 transistors. The **80486**, released in 1989, had more than a million.



1986 INTEL 386 CHIP

In 1991, CERN (European Organization for Nuclear Research) introduced the **World Wide Web**, developed by **Tim Berners-Lee**.

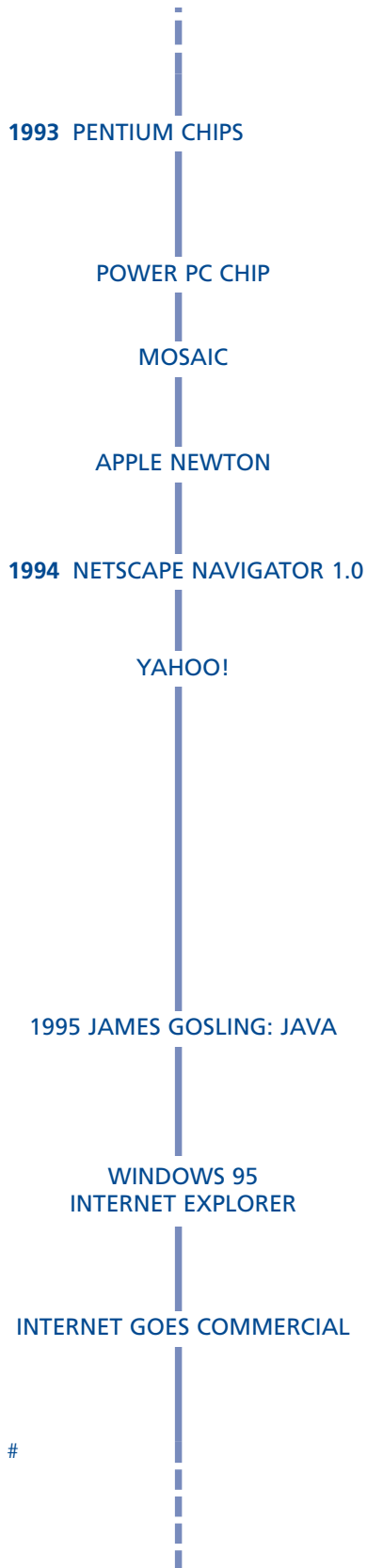


1991 TIM BERNERS-LEE: WWW

In 1992, Linus Torvalds developed **Linux**, a free version of the Unix operating system for PCs.

1992 LINUX

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Several noteworthy things happened in 1993:

- Intel introduced the 64-bit Pentium chip containing more than 3 million transistors. The Pentium Pro released in 1995 had more than 5.5 million. The Pentium II followed in 1997 with 7.5 million transistors, and the Pentium III in 1999 with more than 10 million.

- Motorola shipped the first PowerPC chip.

- The National Center for Supercomputing Applications (NCSA) at the University of Illinois released the first version of Mosaic, the first graphical Web browser.

- Apple introduced the Newton, the first “palmtop” computer.

In 1994

- Netscape Navigator 1.0 was released.

- Yahoo!, the first major Web index, went online. It was started in April 1994 by Electrical Engineering Ph.D. candidates at Stanford University, David Filo and Jerry Yang, as a way to keep track of their personal interests on the Internet.

- Jeff Hawkins and Donna Dubinsky founded Palm Computing. The first Pilot was shipped in 1996.

In 1995, the new C++-based object-oriented programming language Oak, developed at Sun Microsystems by James Gosling, was renamed Java and burst onto the computer scene. Applications created in Java can be deployed without modification to any computing platform, thus making versions for different platforms unnecessary.

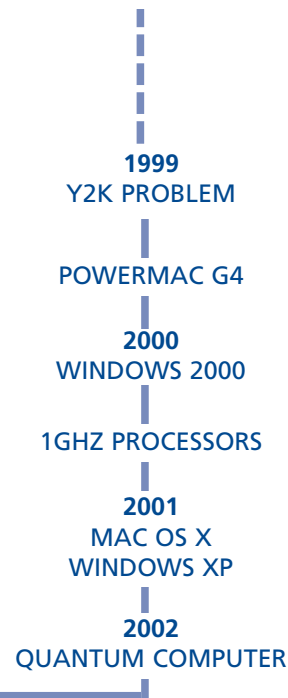
Other important events in 1995

- Microsoft introduced Windows 95.

- Microsoft released Microsoft Internet Explorer 1.0 to compete with the unforeseen popularity of Netscape.

- The U.S. Government turned the maintenance of the Internet backbone over to commercial networking companies. Commercial traffic was now allowed on the Internet. America Online, Compuserve, and Prodigy brought the Internet to the public.

- In 1999 more than \$300 billion was spent worldwide in the years leading up to Jan. 1, 2000 to solve the Y2K problem (also known as the millennium bug) —the inability of old hardware and software to recognize the century change because years were stored with only two digits.
- Apple released the PowerMac G4
- In 2000 Microsoft launched Windows 2000
- AMD's Athlon and Intel's Pentium III broke the 1GHz barrier.
- In 2001 Apple released MacOS X
- Microsoft released Windows XP
- IBM's Almaden Research Center unveiled a quantum computer.



This summary of the history of computing has dealt mainly with the first two important concepts that have shaped the history of computers: the mechanization of arithmetic and the stored program concept. Looking back, we marvel at the advances in technology that have, in barely 50 years, led from ENIAC to today's large array of computer systems, ranging from portable palmtop, laptop, and notebook computers to powerful desktop machines known as workstations, to supercomputers capable of performing billions of operations each second, and to massively parallel computers, which use thousands of microprocessors working together in parallel to solve large problems. Someone once noted that if progress in the automotive industry had been as rapid as in computer technology since 1960, today's automobile would have an engine that is less than 0.1 inch in length, would get 120,000 miles to a gallon of gas, have a top speed of 240,000 miles per hour, and would cost \$4.

We have also seen how the stored program concept has led to the development of large collections of programs that make computers easier to use. Chief among these is the development of operating systems, such as UNIX, Linux, MS-DOS, MacOS and Windows, that allocate memory for programs and data and carry out many other supervisory functions. They also act as an interface between the user and the machine, interpreting commands given by the user from the keyboard, by a mouse click, or by a spoken command and then directing the appropriate system software and hardware to carry them out.

The Graphical User Interface

The third key concept that has produced revolutionary change in the evolution of the computer is the graphical user interface (GUI). A user interface is the portion of a software program that responds to commands from the user. User interfaces have evolved greatly in the past two decades, in direct correlation to equally dramatic changes in the typical computer user.

In the early 1980s, the personal computer burst onto the scene. However, at the outset, the personal computer did not suit the average person very well. The explosion in the amount of commercially available application software spared computer users the task of learning to program in order to compose their own software; for example, the mere availability of the Lotus 1-2-3 spreadsheet software was enough to convince many to buy a PC. Even so, using a computer still required learning many precise and cryptic commands, if not outright programming skills.

In the early 1980s, the Apple Corporation decided to take steps to remedy this situation. The Apple II, like its new competitor, the IBM PC, employed a command-line interface, requiring users to learn difficult commands. In the late 1970s, Steve Jobs had visited Xerox PARC and had viewed several technologies that amazed him: the laser printer, Ethernet, and the graphical user interface. It was the last of these that excited Jobs the most, for it offered the prospect of software that computer users could understand almost intuitively. In 1995 interview he said, "I remember within ten minutes of seeing the graphical user interface stuff, just knowing that every computer would work this way some day."

Drawing upon child development theories, Xerox PARC had developed the graphical user interface for a prototype computer called the Alto that had been realized in 1972. The Alto featured a new device that had been dubbed a "mouse" by its inventor, PARC research scientist Douglas Engelbart. The mouse allowed the user to operate the computer by pointing to icons and selecting options from menus. At the time, however, the cost of the hardware the Alto required made it unfeasible to market, and the brilliant concept went unused. Steve Jobs saw, however, that the same remarkable change in the computer hardware market that had made the personal computer feasible also made the graphical user interface a reasonable possibility. In 1984, in a famous commercial first run during half-time of the Super Bowl, Apple introduced the first GUI personal computer to the world: the Macintosh. In 1985, Microsoft responded with a competing product, the Windows operating system, but until Windows version 3.0 was released in 1990, Macintosh reigned unchallenged in the world of GUI microcomputing. Researchers at the Massachusetts Institute of Technology also brought GUI to the UNIX platform with the release of the X Window system in 1984.

The graphical user interface has made computers easy to use and has produced many new computer users. At the same time, it has greatly changed the character of computing: computers are now expected to be "user friendly." The personal computer, especially, must indeed be "personal" for the average person and not just for computer programmers.

Networks

The computer network is a fourth key concept that has greatly influenced the nature of modern computing. Defined simply, a computer network consists of two or more computers that have been connected in order to exchange resources. This could be hardware resources such as processing power, storage, or access to a printer; software resources such as a data file or access to a computer program; or messages between humans such as electronic mail or multimedia World Wide Web pages.

As computers became smaller, cheaper, more common, more versatile, and easier to use, computer use rose and with it, the number of computer users. Thus, computers had to be shared. In the early 1960s, timesharing was introduced, in which several persons make simultaneous use of a single computer called a host by way of a collection of terminals, each of which consists of a keyboard for input and either a printer or a monitor to display out-

put. With a modem (short for “modulator/demodulator,” because it both modulates binary digits into sounds that can travel over a phone line and, at the other end, demodulates such sounds back into bits), such a terminal connection could be over long distances.

Users, however, began to wish for the ability for one host computer to communicate with another. For example, transferring files from one host to another typically meant transporting tapes from one location to the other. In the late 1960s, the Department of Defense began exploring the development of a computer network by which its research centers at various universities could share their computer resources with each other. In 1969, the ARPANET began by connecting research center computers, enabling them to share software and data and to perform another kind of exchange that surprised everyone in terms of its popularity: electronic mail. Hosts were added to the ARPANET backbone in the 1970s, 1980s, and 1990s at an exponential rate, producing a global digital infrastructure that came to be known as the Internet.

Likewise, with the introduction of microcomputers in the late 1970s and early 1980s, users began to desire the ability for PCs to share resources. The invention of Ethernet network hardware and such network operating systems as Novell NetWare produced the Local Area Network, or LAN, enabling PC users to share printers and other peripherals, disk storage, software programs, and more. Microsoft also included networking capability as a major feature of its Windows NT.

The growth of computer connectivity continues today at a surprising rate. Computers are becoming more and more common, and they are used in isolation less and less. With the advent of affordable and widely available Internet Service Providers (ISPs), many home computers are now “wired” into a growing global digital infrastructure.