

History of Computers

Computing hardware has been an essential component of the process of calculation and data storage since it became useful for numerical values to be processed and shared. The earliest computing hardware was probably some form of tally stick; later recording devices include the Phoenician clay shapes which represented counts of items, probably livestock or grains, in containers. These seem to have been used by the merchants, accountants, and government officials of the time.

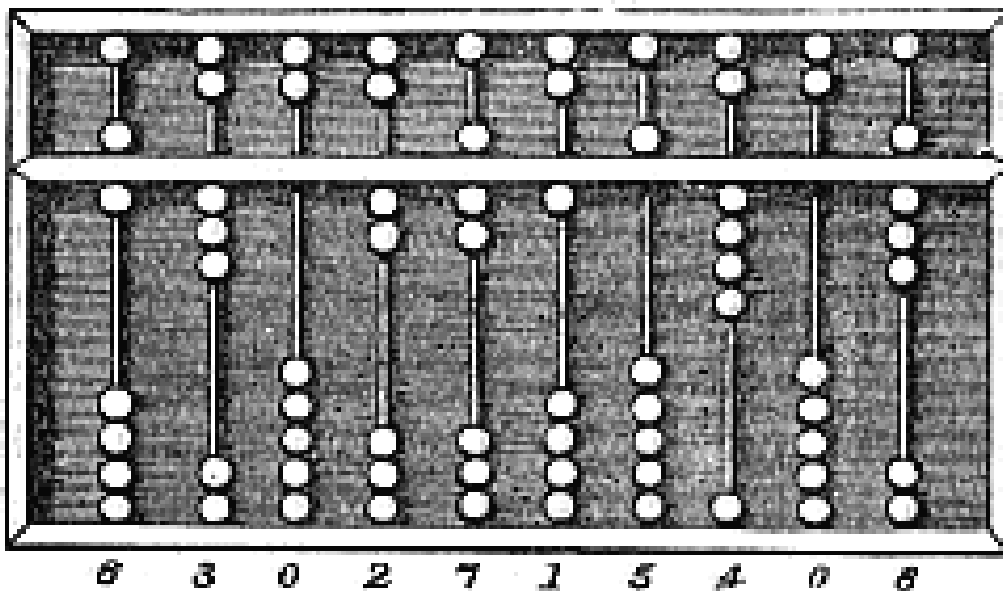
Devices to aid computation have evolved from simple recording and counting devices through the abacus, the slide rule, and more recent electronic computers. Even today, an experienced abacus user using a device designed hundreds of years ago can sometimes complete basic calculations more quickly than an unskilled person using an electronic calculator - though for more complex calculations, computers out-perform even the most skilled human.

This article presents the major developments in the history of computing hardware and attempts to put them in context.

Earliest devices

Humanity has used devices to aid in computation for millennia.

One example is a device for establishing equality by weight: the classic scales, later used to symbolize equality in justice. Another is simple enumeration: the checkered cloths of the counting houses served as simple data structures for enumerating stacks of coins, by weight. A more arithmetic-oriented machine is the abacus. One of the earliest machines of this type was the Chinese abacus.



Chinese and others frustrated with counting on their fingers invented the Abacus

First mechanical calculators

In 1623 Wilhelm Schickard built the first mechanical calculator and thus became the father of the computing era.

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Gears are at the heart of mechanical devices like the Curta calculator

As early as the 1640's mechanical calculators are manufactured for sale. Records exist of earlier machines, but Blaise Pascal invents the first commercial calculator, a hand powered adding machine. Although attempts to multiply mechanically were made by Gottfried Liebnitz in the 1670s the first true multiplying calculator appears in Germany shortly before the American Revolution.

In 1801 a Frenchman, Joseph-Marie Jacquard builds a loom that weaves by reading punched holes stored on small sheets of hardwood. These plates are then inserted into the loom which reads (retrieves) the pattern and creates(process) the weave. Powered by water, this "machine" came 140 years before the development of the modern computer.

Shortly after the first mass-produced calculator(1820), Charles Babbage begins his lifelong quest for a programmable machine. Although Babbage was a poor communicator and record-keeper, his difference engine is sufficiently developed by 1842 that Ada Lovelace uses it to mechanically translate a short written work. She is generally regarded as the first programmer. Twelve years later George Boole, while professor of Mathematics at Cork University, writes An Investigation of the Laws of Thought(1854), and is generally recognized as the father of computer science.

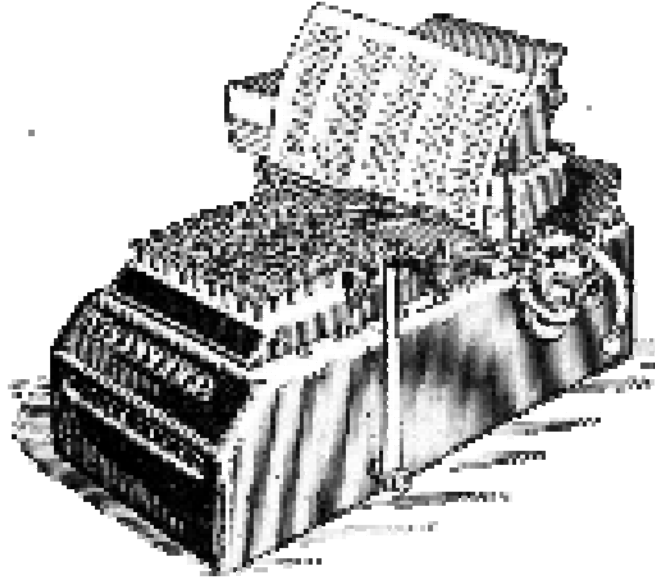


The 1890 census is tabulated on punch cards similar to the ones used 90 years earlier to create weaves. Developed by Herman Hollerith of MIT, the system uses electric power(non-mechanical). The Hollerith Tabulating Company is a forerunner of today's IBM.

Just prior to the introduction of Hollerith's machine the first printing calculator is introduced. In 1892 William Burroughs, a sickly ex-teller, introduces a commercially successful printing calculator. Although hand-powered, Burroughs quickly introduces an electronic model.

Since his machine used techniques such as cogs and gears first developed for clocks, it was also called a 'calculating clock'. It was put to practical use by his friend Johannes Kepler, who revolutionized astronomy.

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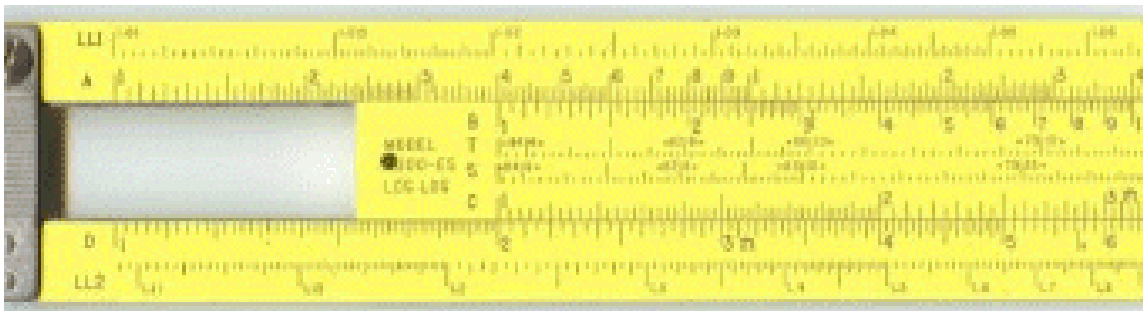


Mechanical calculator from 1914

Machines by Blaise Pascal (the Pascaline, 1642) and Gottfried Wilhelm von Leibniz (1671) followed. Around 1820, Charles Xavier Thomas created the first successful, mass-produced mechanical calculator, the Thomas Arithmometer, that could add, subtract, multiply, and divide. It was mainly based on Leibniz's work. Mechanical calculators, like the base-ten addiator, the comptometer, the Monroe, the Curta and the Addo-X remained in use until the 1970s.

Leibniz also described the binary numeral system, a central ingredient of all modern computers. However, up to the 1940s, many subsequent designs (including Charles Babbage's machines of the 1800s and even ENIAC of 1945) were based on the harder-to-implement decimal system.

John Napier noted that multiplication and division of numbers can be performed by addition and subtraction, respectively, of logarithms of those numbers. Since these real numbers can be represented as distances or intervals on a line, the slide rule allowed multiplication and division operations to be carried significantly faster than was previously possible. Slide rules were used by generations of engineers and other mathematically inclined professional workers, until the invention of the pocket calculator. The engineers in the Apollo program to send a man to the moon made many of their calculations on slide rules, which were accurate to 3 or 4 significant figures.



The slide rule, a basic mechanical calculator, facilitates multiplication and division

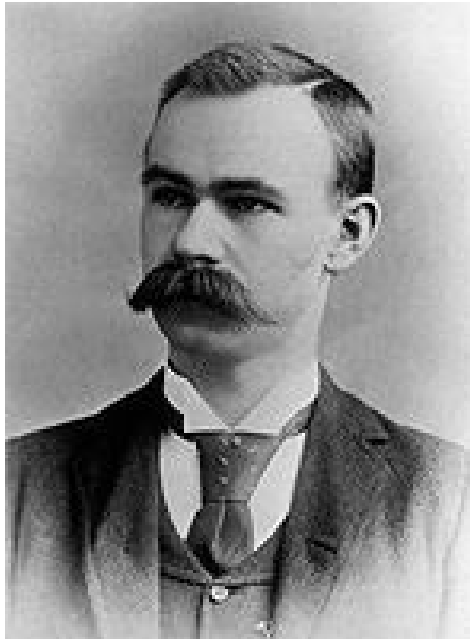
While producing the first logarithmic tables Napier needed to perform many multiplications and it was at this point that he designed Napier's bones.

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1801: punched card technology

In 1801, Joseph-Marie Jacquard developed a loom in which the pattern being woven was controlled by punched cards. The series of cards could be changed without changing the mechanical design of the loom. This was a landmark point in programmability.

In 1833, Charles Babbage moved on from developing his difference engine to developing a more complete design, the analytical engine which would draw directly on Jacquard's punch cards for its programming.



Herman Hollerith invented a tabulating machine using punch cards in the 1880s.



Charles Babbage

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In 1890, the United States Census Bureau used punch cards and sorting machines designed by Herman Hollerith to handle the flood of data from the decennial census mandated by the Constitution. Hollerith's company eventually became the core of IBM. IBM developed punch card technology into a powerful tool for business data processing and produced an extensive line of specialized unit record equipment. By 1950 the IBM card had become ubiquitous in industry and government. The warning printed on most cards, "Do not fold, spindle or mutilate", became a motto for the post-World War II era.

Leslie Comrie's articles on punch card methods and W.J. Eckert's publication of Punched Card Methods in Scientific Computation in 1940, described techniques which were sufficiently advanced to solve differential equations, perform multiplication and division using floating point representations, all on punched cards and plug-boards similar to those used by telephone operators. The Thomas J. Watson Astronomical Computing Bureau, Columbia University performed astronomical calculations representing the state of the art in computing.

In many computer installations, punched cards were used until (and after) the end of the 1970s. For example, science and engineering students at many universities around the world would submit their programming assignments to the local computer centre in the form of a stack of cards, one card per program line, and then had to wait for the program to be queued for processing, compiled, and executed. In due course a printout of any results, marked with the submitter's identification, would be placed in an output tray outside the computer center. In many cases these results would comprise solely a printout of error messages regarding program syntax etc., necessitating another edit-compile-run cycle.

Punched cards are still used and manufactured in the current century, and their distinctive dimensions (and 80-column capacity) can still be recognised in forms, records, and programs around the world.

1835-1900s: first programmable machines

The defining feature of a "universal computer" is programmability, which allows the computer to emulate any other calculating machine by changing a stored sequence of instructions.

In 1835 Charles Babbage described his analytical engine. It was the plan of a general-purpose programmable computer, employing punch cards for input and a steam engine for power. One crucial invention was to use gears for the function served by the beads of an abacus. In a real sense, computers all contain automatic abacuses (technically called the ALU or floating-point unit).

His initial idea was to use punch-cards to control a machine that could calculate and print logarithmic tables with huge precision (a specific purpose machine). Babbage's idea soon developed into a general-purpose programmable computer, his analytical engine.

While his design was sound and the plans were probably correct, or at least debuggable, the project was slowed by various problems. Babbage was a difficult man to work with and argued with anyone who didn't respect his ideas. All the parts for his machine had to be made by hand and small errors in each item were summed up as huge discrepancies in a machine with thousands of parts. The project dissolved over disputes with the artisan who built parts and was ended with the depletion of government funding.

Ada Lovelace, Lord Byron's daughter, translated and added notes to the "Sketch of the Analytical Engine" by Federico Luigi, Conte Menabrea. She has become closely associated with Babbage. Some claim she is the world's first computer programmer, however this claim and the value of her other contributions are disputed by many.

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Augusta Ada King, Countess of Lovelace

A reconstruction of the Difference Engine II, an earlier, more limited design, has been operational since 1991 at the London Science Museum. With a few trivial changes, it works as Babbage designed it and shows that Babbage was right in theory.

The museum used computer-operated machine tools to construct the necessary parts, following tolerances which a machinist of the period would have been able to achieve. Some feel that the technology of the time was unable to produce parts of sufficient precision, though this appears to be false. The failure of Babbage to complete the engine can be chiefly attributed to difficulties not only related to politics and financing, but also to his desire to develop an increasingly sophisticated computer. Today, many in the computer field term this sort of obsession creeping featuritis.

Following in the footsteps of Babbage, although unaware of his earlier work, was Percy Ludgate, an accountant from Dublin, Ireland. He independently designed a programmable mechanical computer, which he described in a work that was published in 1909.

1930s-1960s: desktop calculators

By the 1900s earlier mechanical calculators, cash registers, accounting machines, and so on were redesigned to use electric motors, with gear position as the representation for the state of a variable. Companies like Friden, Marchant and Monroe made desktop mechanical calculators from the 1930s that could add, subtract, multiply and divide. The word "computer" was a job title assigned to people who used these calculators to perform mathematical calculations. During the Manhattan project, future Nobel laureate Richard Feynman was the supervisor of the roomful of human computers, many of them women mathematicians, who understood the differential equations which were being solved for the war effort. Even the renowned Stanislaw Marcin Ulam was pressed into service to translate the mathematics into computable approximations for the hydrogen bomb, after the war.

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In 1948, the Curta was introduced. This was a small, portable, mechanical calculator that was about the size of a pepper grinder. Over time, during the 1950s and 1960s a variety of different brands of mechanical calculator appeared on the market.

The first desktop electronic calculator was probably Sumlock Comptometer's 1961 Anita C/VIII, which used a Nixie tube display and 177 subminiature thyratron tubes. In June 1963, Friden introduced the four-function EC-130. It had an all-transistor design, 13-digit capacity on a 5-inch CRT, and introduced reverse Polish notation (RPN) to the calculator market at a price of \$2200. The model EC-132 added square root and reciprocal functions. In 1965, Wang Laboratories produced the LOCI-2, a 10-digit transistorized desktop calculator that used a Nixie tube display and could compute logarithms.

In 1925, unaware of the work of Charles Babbage, Vannevar Bush of MIT builds a machine he calls the differential analyzer. Using a set of gears and shafts, much like Babbage, the machine can handle simple calculus problems, but accuracy is a problem.

The period from 1935 through 1952 gets murky with claims and counterclaims of who invents what and when. Part of the problem lies in the international situation that makes much of the research secret. Other problems include poor record-keeping, deception and lack of definition.

In 1935, Konrad Zuse, a German construction engineer, builds a mechanical calculator to handle the math involved in his profession. Shortly after completion, Zuse starts on a programmable electronic device which he completes in 1938.



John Vincent Atanasoff begins work on a digital computer in 1936 in the basement of the Physics building on the campus of Iowa State. A graduate student, Clifford (John) Berry assists. The "ABC" is designed to solve linear equations common in physics. It displays some early features of later computers including electronic calculations. He shows it to others in 1939 and leaves the patent application with attorneys for the school when he leaves for a job in Washington during World War II. Unimpressed, the school never files and ABC is cannibalized by students.



The Enigma, a complex mechanical encoder is used by the Germans and they believe it to be unbreakable. Several people involved, most notably Alan Turing, conceive machines to handle the problem, but none are technically feasible. Turing proposes a "Universal Machine" capable of "computing" any algorithm in 1937. That same year George Steblitz creates his Model K(itchen), a conglomeration of otherwise useless and leftover material, to solve complex calculations. He improves the design while working at Bell Labs and on September 11, 1940, Steblitz uses a teletype machine at Dartmouth College in New Hampshire to transmit a problem to his Complex Number Calculator in New York

and receives the results. It is the first example of a network. First in Poland, and later in Great Britain and the United States, the Enigma code is broken. Information gained by this shortens the war. To break the code, the British, led by Turing, build the Colossus Mark I. The existence of this machine is

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a closely guarded secret of the British Government until 1970. The United States Navy, aided to some extent by the British, builds a machine capable of breaking not only the German code but the Japanese code as well.

In 1943 development begins on the Electronic Numerical Integrator And Computer (ENIAC) in earnest at Penn State. Designed by John Mauchly and J. Presper Eckert of the Moore School, they get help from John von Neumann and others. In 1944, the Harvard Mark I is introduced. Based on a series of proposals from Howard Aiken in the late 1930's, the Mark I computes complex tables for the U.S. Navy. It uses a paper tape to store instructions and Aiken hires Grace Hopper("Amazing Grace") as one of three programmers working on the machine. Thomas J. Watson Sr. plays a pivotal role involving his company, IBM, in the machine's development.

Early in 1945, with the Mark I stopped for repairs, Hopper notices a moth in one of the relays, possibly causing the problem. From this day on, Hopper refers to fixing the system as "debugging". The same year Von Neumann proposes the concept of a "stored program" in a paper that is never officially published.

With development of the integrated circuits and microprocessors, the expensive, large calculators were replaced with smaller electronic devices.

Pre-1940 analog computers

Before World War II, mechanical and electrical analog computers were considered the 'state of the art', and many thought they were the future of computing. Analog computers use continuously varying amounts of physical quantities, such as voltages or currents, or the rotational speed of shafts, to represent the quantities being processed. An ingenious example of such a machine was the Water integrator built in 1936. Unlike modern digital computers, analog computers are not very flexible, and need to be reconfigured (i.e., reprogrammed) manually to switch them from working on one problem to another. Analog computers had an advantage over early digital computers in that they could be used to solve complex problems while the earliest attempts at digital computers were quite limited. But as digital computers have become faster and used larger memory (e.g., RAM or internal store), they have almost entirely displaced analog computers, and computer programming, or coding has arisen as another human profession.

Since computers were rare in this era, the solutions were often hard-coded into paper forms such as graphs and nomograms, which could then allow analog solutions to problems, such as the distribution of pressures and temperatures in a heating system.

Some of the most widely deployed analog computers included devices for aiming weapons, such as the Norden bombsight and artillery aiming computers for battleships. Some of these stayed in use for decades after WWII.

Hybrid analog computers, controlled by digital electronics, remained in substantial use into the 1950s and 1960s, and later in some specialised applications.

1940s: first electrical digital computers

The era of modern computing began with a flurry of development before and during World War II, as electronic circuits, relays, capacitors and vacuum tubes replaced mechanical equivalents and digital calculations replaced analog calculations. The computers designed and constructed then have sometimes been called 'first generation' computers. First generation computers such as the Atanasoff-Berry Computer, Z3 and Colossus were built by hand using circuits containing relays or vacuum valves (tubes), and often used punched cards or punched paper tape for input and as the main (non-volatile) storage medium. Temporary, or working storage, was provided by acoustic delay lines (which

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use the propagation time of sound in a medium such as wire to store data) or by Williams tubes (which use the ability of a television picture tube to store and retrieve data). By 1954, magnetic core memory was rapidly displacing most other forms of temporary storage, and dominated the field through the mid-1970s.

In this era, a number of different machines were produced with steadily advancing capabilities. At the beginning of this period, nothing remotely resembling a modern computer existed, except in the long-lost plans of Charles Babbage and the mathematical musings of Alan Turing and others. At the end of the era, devices like the EDSAC had been built, and are universally agreed to be digital computers. Defining a single point in the series as the "first computer" misses many subtleties.

Alan Turing's 1936 paper has proved enormously influential in computing and computer science in two ways. Its main purpose was an elegant proof that there were problems (namely the halting problem) that could not be solved by a mechanical process (a computer). In doing so, however, Turing provided a definition of what a universal computer is: a construct called the Turing machine, a purely theoretical device invented to formalize the notion of algorithm execution, replacing Kurt Gödel's more cumbersome universal language based on arithmetics. Modern computers are Turing-complete (i.e., equivalent algorithm execution capability to a universal Turing machine), except for their finite memory. This limited type of Turing completeness is sometimes viewed as a threshold capability separating general-purpose computers from their special-purpose predecessors.

However, as will be seen, theoretical Turing-completeness is a long way from a practical universal computing device. To be a practical general-purpose computer, there must be some convenient way to input new programs into the computer, such as punched tape. For full versatility, the Von Neumann architecture uses the same memory both to store programs and data; virtually all contemporary computers use this architecture (or some variant). Finally, while it is theoretically possible to implement a full computer entirely mechanically (as Babbage's design showed), electronics made possible the speed and later the miniaturization that characterises modern computers.

There were three parallel streams of computer development in the World War II era, and two were either largely ignored or were deliberately kept secret. The first was the German work of Konrad Zuse. The second was the secret development of the Colossus computer in the UK. Neither of these had much influence on the various computing projects in the United States. After the war, British and American computing researchers cooperated on some of the most important steps towards a practical computing device.

American developments

In 1937, Claude Shannon produced his master's thesis at MIT that implemented Boolean algebra using electronic relays and switches for the first time in history. Entitled A Symbolic Analysis of Relay and Switching Circuits, Shannon's thesis essentially founded practical digital circuit design.

In November of 1937, George Stibitz, then working at Bell Labs, completed a relay-based computer he dubbed the "Model K" (for "kitchen", where he had assembled it), which calculated using binary addition. Bell Labs thus authorized a full research program in late 1938 with Stibitz at the helm. Their Complex Number Calculator, completed January 8, 1940, was able to calculate complex numbers. In a demonstration to the American Mathematical Society conference at Dartmouth College on September 11, 1940, Stibitz was able to send the Complex Number Calculator remote commands over telephone lines by a teletype. It was the first computing machine ever used remotely over a phone line. Some participants of the conference who witnessed the demonstration were John Von Neumann, John Mauchly, and Norbert Wiener, who wrote about it in his memoirs.

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In 1938 John Vincent Atanasoff and Clifford E. Berry of Iowa State University developed the Atanasoff-Berry Computer (ABC), a special purpose electronic computer for solving systems of linear equations. The design used over 300 vacuum tubes for high speed and employed capacitors fixed in a mechanically rotating drum for memory. Though the ABC machine was not programmable, it was the first modern computer in several other respects, including the first to use binary math and electronic circuits. ENIAC co-inventor John Mauchly visited the ABC while it was still under construction in June 1941, and its influence over the design of the ENIAC is a matter of contention among computer historians. The ABC was largely forgotten until it became the focus of the lawsuit *Honeywell v. Sperry Rand*, which invalidated the ENIAC patent.

In 1939, development began at IBM's Endicott laboratories on the Harvard Mark I. Known officially as the Automatic Sequence Controlled Calculator, the Mark I was a general purpose electro-mechanical computer built with IBM financing and with assistance from some IBM personnel under the direction of Harvard mathematician Howard Aiken. Its design was influenced by the Analytical Engine. It was a decimal machine which used storage wheels and rotary switches in addition to electromagnetic relays. It was programmable by punched paper tape, and contained several calculators working in parallel. Later models contained several paper tape readers and the machine could switch between readers based on a condition. Nevertheless, this does not quite make the machine Turing-complete. The Mark I was moved to Harvard University to begin operation in May 1944.

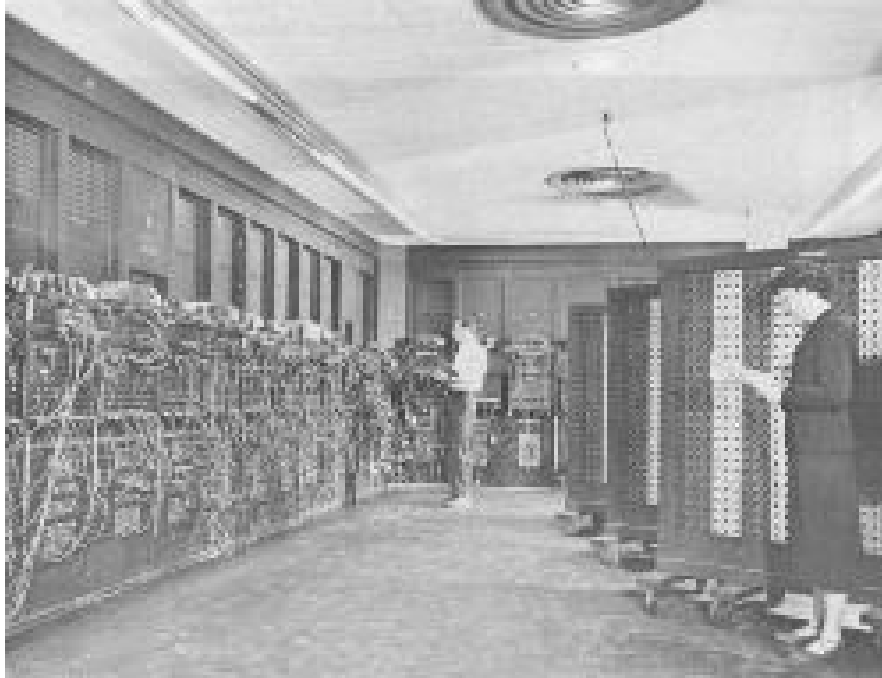
The US-built ENIAC (Electronic Numerical Integrator and Computer), often called the first electronic general-purpose computer, publicly validated the use of electronics for large-scale computing. This was crucial for the development of modern computing, initially because of the enormous speed advantage, but ultimately because of the potential for miniaturization. Built under the direction of John Mauchly and J. Presper Eckert, it was 1,000 times faster than its contemporaries. ENIAC's development and construction lasted from 1941 to full operation at the end of 1945. When its design was proposed, many researchers believed that the thousands of delicate valves (i.e. vacuum tubes) would burn out often enough that the ENIAC would be so frequently down for repairs as to be useless. It was, however, capable of up to thousands of operations per second for hours at a time between valve failures.

ENIAC was unambiguously a Turing-complete device. To 'program' ENIAC, however, meant to rewire it--some say this does not even qualify as programming, otherwise any type of rebuilding some limited computer might be viewed as programming. At the time, however, unaided calculation was seen as enough of a triumph to view the solution of a single problem as the object of a program. (Improvements completed in 1948 made it possible to execute stored programs set in function table memory, which made programming less a one-off effort, and more systematic.)

Work completes on ENIAC in 1946. Although only three years old the machine is woefully behind on technology, but the inventors opt to continue while working on a more modern machine, the EDVAC. Programming ENIAC requires it to be rewired. A later version eliminates this problem. To make the machine appear more impressive to reporters during its unveiling, a team member (possibly Eckert) puts translucent spheres(halved ping pong balls) over the lights. The US patent office will later recognize this as the first computer.

The next year scientists employed by Bell Labs complete work on the transistor (John Bardeen, Walter Brattain and William Shockley receive the Nobel Prize in Physics in 1956), and by 1948 teams around the world work on a "stored program" machine. The first, nicknamed "Baby", is a prototype of a much larger machine under construction in Britain and is shown in June 1948.

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**ENIAC performed ballistics trajectory calculations with 160 kW of power.
Source: U.S. Army**

Jon von Neumann, based on ideas developed by Eckhart and Mauchly after recognising the limitations of ENIAC, wrote a widely-circulated report describing a computer design (the EDVAC design) in which the programs and working data were both stored in a single, unified store. This basic design, which became known as the von Neumann architecture, would serve as the basis for the development of the first really flexible, general-purpose digital computers.

Colossus

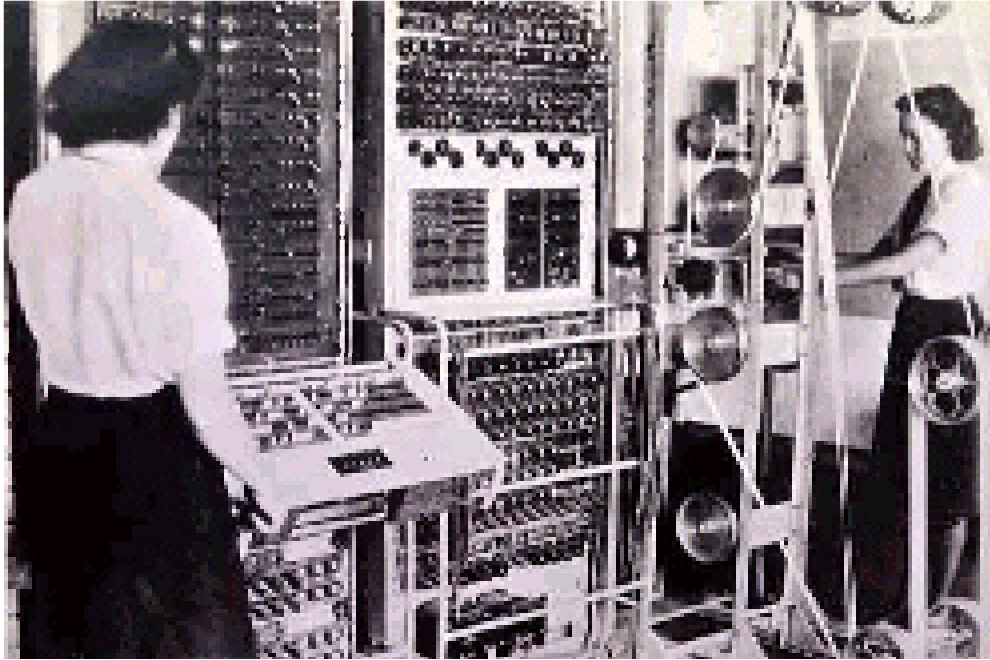
During World War II, the British at Bletchley Park achieved a number of successes at breaking encrypted German military communications. The German encryption machine, Enigma, was attacked with the help of electro-mechanical machines called bombes. The bombe, designed by Alan Turing and Gordon Welchman, after Polish bomba, ruled out possible Enigma settings by performing chains of logical deductions implemented electrically. Most possibilities led to a contradiction, and the few remaining could be tested by hand.

The Germans also developed a series of teleprinter encryption systems, quite different from Enigma. The Lorenz SZ 40/42 machine was used for high-level Army communications, termed "Tunny" by the British. The first intercepts of Lorenz messages began in 1941. As part of an attack on Tunny, Professor Max Newman and his colleagues helped specify the Colossus. The Mk I Colossus was built in 11 months by Tommy Flowers and his colleagues at the Post Office Research Station at Dollis Hill in London and then shipped to Bletchley Park.

Colossus was the first totally electronic computing device. The Colossus used a large number of valves (vacuum tubes). It had paper-tape input and was capable of being configured to perform a variety of boolean logical operations on its data, but it was not Turing-complete. Nine Mk II Colossi were built (The Mk I was converted to a Mk II making ten machines in total). Details of their existence, design, and use were kept secret well into the 1970s. Winston Churchill personally issued an order for their destruction into pieces no larger than a man's hand. Due to this secrecy the Colossi were not

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included in many histories of computing. A reconstructed copy of one of the Colossus machines is now on display at Bletchley Park.



Colossus was used to break German ciphers during World War II

Konrad Zuse's Z-series

Working in isolation in Nazi Germany, Konrad Zuse started construction in 1936 of his first Z-series calculators featuring memory and (initially limited) programmability. Zuse's purely mechanical, but already binary Z1, finished in 1938, never worked reliably due to problems with the precision of parts.



A reproduction of Zuse's Z1 computer

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Zuse's subsequent machine, the Z3, was finished in 1941. It was based on telephone relays and did work satisfactorily. The Z3 thus became the first functional program-controlled computer. In many ways it was quite similar to modern machines, pioneering numerous advances, such as floating point numbers. Replacement of the hard-to-implement decimal system (used in Charles Babbage's earlier design) by the simpler binary system meant that Zuse's machines were easier to build and potentially more reliable, given the technologies available at that time. This is sometimes viewed as the main reason why Zuse succeeded where Babbage failed.

Programs were fed into Z3 on punched films. Conditional jumps were missing, but since the 1990s it has been proved theoretically that Z3 was still a universal computer (ignoring its physical storage size limitations). In two 1937 patents, Konrad Zuse also anticipated that machine instructions could be stored in the same storage used for data - the key insight of what became known as the Von Neumann architecture and was first implemented in the later British EDSAC design (1949). Zuse also claimed to have designed the first higher-level programming language, (Plankalkül), in 1945, although it was never formally published until 1971, and was implemented for the first time in 2000 by the Free University of Berlin -- five years after Zuse died.

Zuse suffered setbacks during World War II when some of his machines were destroyed in the course of Allied bombing campaigns. Apparently his work remained largely unknown to engineers in the UK and US until much later, although at least IBM was aware of it as it financed his post-war startup company in 1946 in return for an option on Zuse's patents.

First generation von Neumann machines

The first working von Neumann machine was the Manchester "Baby" or Small-Scale Experimental Machine, built at the University of Manchester in 1948; it was followed in 1949 by the Manchester Mark I computer which functioned as a complete system using the Williams tube for memory, and also introduced index registers. The other contender for the title "first digital stored program computer" was EDSAC, designed and constructed at the University of Cambridge. Operational less than one year after the Manchester "Baby", it was capable of tackling real problems. EDSAC was actually inspired by plans for EDVAC (Electronic Discrete Variable Automatic Computer), the successor of ENIAC; these plans were already in place by the time the ENIAC was successfully operational. Unlike the ENIAC, which used parallel processing, EDVAC used a single processing unit. This design was simpler and was the first to be implemented in each succeeding wave of miniaturization, and increased reliability. Some view Manchester Mark I / EDSAC / EDVAC as the "Eves" from which nearly all current computers derive their architecture.

The first universal programmable computer in continental Europe was created by a team of scientists under direction of Sergei Alekseyevich Lebedev from Kiev Institute of Electrotechnology, Soviet Union (now Ukraine). The computer MESM (possibly standing for Small Electronic Calculating Machine) became operational in 1950. It had about 6,000 vacuum tubes and consumed 25 kW of power. It could perform approximately 3,000 operations per second. Another early machine was CSIRAC, an Australian design that ran its first test program in 1949.

In October 1947, the directors of J. Lyons & Company, a British catering company famous for its teashops but with strong interests in new office management techniques, decided to take an active role in promoting the commercial development of computers. By 1951 the LEO I computer was operational and ran the world's first regular routine office computer job.

Manchester University's machine became the prototype for the Ferranti Mark I. The first Ferranti Mark I machine was delivered to the University in February, 1951 and at least nine others were sold between 1951 and 1957.

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In June 1951, the UNIVAC I (Universal Automatic Computer) was delivered to the U.S. Census Bureau. Although manufactured by Remington Rand, the machine often was mistakenly referred to as the "IBM UNIVAC". Remington Rand eventually sold 46 machines at more than \$1 million each. UNIVAC was the first 'mass produced' computer; all predecessors had been 'one-off' units. It used 5,200 vacuum tubes and consumed 125 kW of power. It used a mercury delay line capable of storing 1,000 words of 11 decimal digits plus sign (72-bit words) for memory. Unlike earlier machines it did not use a punch card system but a metal tape input.

The impetus over the next 5 years for advances in computers is mostly the government and military. UNIVAC, delivered in 1951 to the Census Bureau, results in a tremendous financial loss to its manufacturer, Remington-Rand. The next year Grace Hopper, now an employee of that company proposes "reusable software," code segments that could be extracted and assembled according to instructions in a "higher level language." The concept of compiling is born. Hopper would revise this concept over the next twenty years and her ideas would become an integral part of all modern computers. CBS uses one of the 46 UNIVAC computers produced to predict the outcome of the 1952 Presidential Election. They do not air the prediction for 3 hours because they do not trust the machine.



UNIVAC I, the first commercial electronic computer, achieved 1900 operations per second in a smaller and more efficient package than ENIAC

In November 1951, the J. Lyons company began weekly operation of a bakery valuations job on the LEO (Lyons Electronic Office). This was the first business application to go live on a stored program computer.

In 1952, IBM publicly announced the IBM 701 Electronic Data Processing Machine, the first in its successful 700/7000 series and its first IBM mainframe computer. The IBM 704, introduced in 1954, used magnetic core memory, which became the standard for large machines. The first implemented high-level general purpose programming language, Fortran, was also being developed at IBM for the 704 during 1955 and 1956 and released in early 1957. (Konrad Zuse's 1945 design of the high-level language Plankalkül was not implemented at that time.)

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IBM introduced a smaller, more affordable computer in 1954 that proved very popular. The IBM 650 weighed over 900 kg, the attached power supply weighed around 1350 kg and both were held in separate cabinets of roughly 1.5 meters by 0.9 meters by 1.8 meters. It cost \$500,000 or could be leased for \$3,500 a month. Its drum memory was originally only 2000 ten-digit words, and required arcane programming for efficient computing. Memory limitations such as this were to dominate programming for decades afterward, until the evolution of a programming model which was more sympathetic to software development.

IBM introduces the 701 the following year. It is the first commercially successful computer. In 1956 FORTRAN is introduced (proposed 1954, it takes nearly 3 years to develop the compiler). Two additional languages, LISP and COBOL, are added in 1957 and 1958. Other early languages include ALGOL and BASIC. Although never widely used, ALGOL is the basis for many of today's languages.



With the introduction of Control Data's CDC1604 in 1958, the first transistor powered computer, a new age dawns. Brilliant scientist Seymour Cray heads the development team. This year integrated circuits are introduced by two men, Jack Kilby and John Noyce, working independently. The second network is developed at MIT. Over the next three years computers begin affecting the day-to-day lives of most Americans. The addition of MICR characters at the bottom of checks is common.

In 1955, Maurice Wilkes invented microprogramming, which was later widely used in the CPUs and floating-point units of mainframe and other computers, such as the IBM 360 series. Microprogramming allows the base instruction set to be defined or extended by built-in programs (now sometimes called firmware, microcode, or millicode).

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Maurice Wilkes realised that basic and frequently used operations could be programmed directly into hardware

In 1956, IBM sold its first magnetic disk system, RAMAC (Random Access Method of Accounting and Control). It used 50 24-inch metal disks, with 100 tracks per side. It could store 5 megabytes of data and cost \$10,000 per megabyte. (As of 2005, disk storage costs less than \$1 per gigabyte).

1950s and early 1960s: second generation

The next major step in the history of computing was the invention of the transistor in 1947. This replaced the fragile and power hungry valves with a much smaller and more reliable component. Transistorized computers are normally referred to as 'Second Generation' and dominated the late 1950s and early 1960s. By using transistors and printed circuits a significant decrease in size and power consumption was achieved, along with an increase in reliability. For example, the transistorized IBM 1620, which replaced the bulky IBM 650, was the size of an office desk. Second generation computers were still expensive and were primarily used by universities, governments, and large corporations.



Transistors, above, revolutionized computers as smaller and more efficient replacements for vacuum tubes

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In 1959 IBM shipped the transistor-based IBM 7090 mainframe and medium scale IBM 1401. The latter was designed around punch card input and proved a popular general purpose computer. Some 12,000 were shipped, making it the most successful machine in computer history at the time. It used a magnetic core memory of 4000 characters (later expanded to 16,000 characters). Many aspects of its design were based on the desire to replace punched card machines which were in wide use from the 1920s through the early 1970s.

In 1960 IBM shipped the smaller, transistor-based IBM 1620, originally with only punched paper tape, but soon upgraded to punch cards. It proved a popular scientific computer and about 2,000 were shipped. It used a magnetic core memory of up to 60,000 decimal digits.

Also in 1960, DEC launched the PDP-1 their first machine intended for use by technical staff in laboratories and for research.



Digital Equipment Corporation's first computer was the PDP-1

It was built mostly of DEC 1000-series system modules, using Micro-Alloy and Micro-Alloy-Diffused Transistors

In 1961, Burroughs released the B5000 the first dual processor and virtual memory computer. Other unique features were a stack architecture, descriptor-based addressing, and no programming directly in assembly language.

In 1961 Fairchild Semiconductor introduces the integrated circuit. Within ten years all computers use these instead of the transistor. Formally building sized computers are now room-sized, and are

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considerably more powerful. The following year the Atlas becomes operational, displaying many of the features that make today's systems so powerful including virtual memory, pipeline instruction execution and paging. Designed at the University of Manchester, some of the people who developed Colossus thirty years earlier make contributions.

In 1962, Sperry Rand shipped the UNIVAC 1107, one of the first machines with a general register set and the base of the successful UNIVAC 1100 series.

On April 7, 1964, IBM introduces the System/360. While a technical marvel, the main feature of this machine is business oriented...IBM guarantees the "upward compatibility" of the system, reducing the risk that a business would invest in outdated technology. Dartmouth College, where the first network was demonstrated 25 years earlier, moves to the forefront of the "computer age" with the introduction of TSS(Time Share System) a crude(by today's standards) networking system. It is the first Wide Area Network. In three years Randy Golden, President and Founder of Golden Ink, would begin working on this network.

Within a year MIT returns to the top of the intellectual computer community with the introduction of a greatly refined network that features shared resources and uses the first minicomputer(DEC's PDP-8) to manage telephone lines. Bell Labs and GE play major roles in its design.

In 1964 IBM announced the S/360 series, which was the first family of computers that could run the same software at different combinations of speed, capacity and price. It also pioneered the commercial use of microprograms, and an extended instruction set designed for processing many types of data, not just arithmetic. In addition, it unified IBM's product line, which prior to that time had included both a "commercial" product line and a separate "scientific" line. The software provided with System/360 also included major advances, including commercially available multi-programming, new programming languages, and independence of programs from input/output devices. Over 14,000 System/360 systems were shipped by 1968.

Also in 1964, DEC launched the PDP-8 much smaller machine intended for use by technical staff in laboratories and for research.

In 1969 Bell Labs, unhappy with the direction of the MIT project, leaves and develops its own operating system, UNIX. One of the many precursors to today's Internet, ARPANet, is quietly launched. Alan Keys, who will later become a designer for Apple, proposes the "personal computer." Also in 1969, unhappy with Fairchild Semiconductor, a group of technicians begin discussing forming their own company. This company, formed the next year, would be known as Intel. The movie Colossus:The Forbin Project has a supercomputer as the villain. Next year, The Computer Wore Tennis Shoes was the first feature length movie with the word computer in the title. In 1971, Texas Instruments introduces the first "pocket calculator." It weighs 2.5 pounds.

Post-1960: third generation and beyond

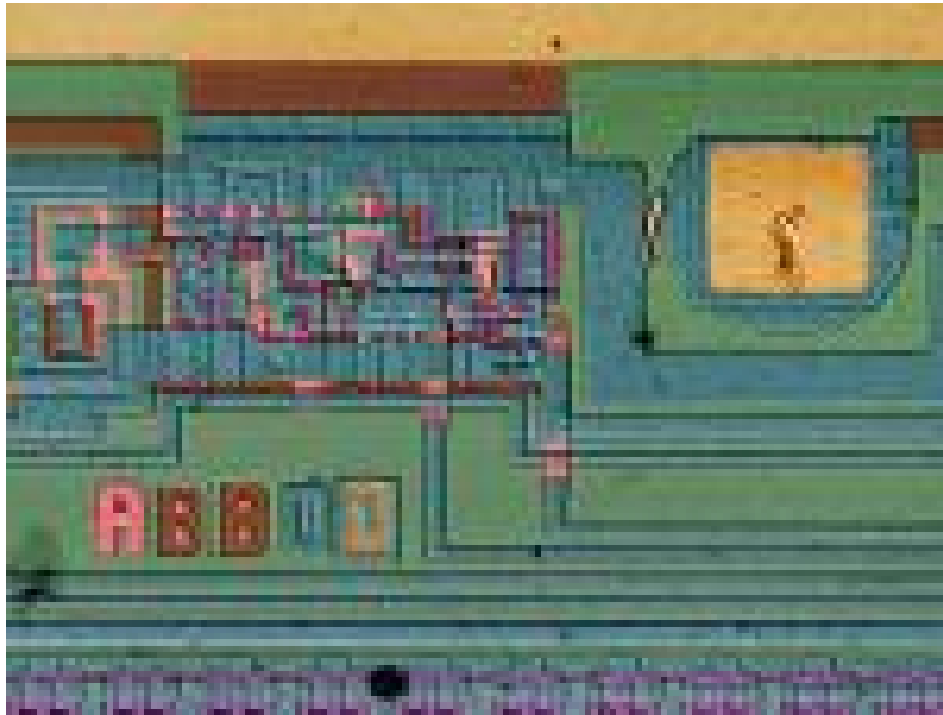
The explosion in the use of computers began with 'Third Generation' computers. These relied on Jack St. Clair Kilby's and Robert Noyce's independent invention of the integrated circuit (or microchip), which later led to Ted Hoff's invention of the microprocessor, at Intel.

During the 1960s there was considerable overlap between second and third generation technologies. As late as 1975, Sperry Univac continued the manufacture of second-generation machines such as the UNIVAC 494.

The microprocessor led to the development of the microcomputer, small, low-cost computers that could be owned by individuals and small businesses. Microcomputers, the first of which appeared in

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the 1970s, became ubiquitous in the 1980s and beyond. Computing has evolved with microcomputer architectures, with features added from their larger brethren, now dominant in most market segments.



The microscopic integrated circuit, above, combined many hundreds of transistors into one unit for fabrication

With the country embroiled in a crisis of confidence known as Watergate, in 1973 a little publicized judicial decision takes the patent for the computer away from Mauchly and Eckert and awards it to Atanasoff. Xerox introduces the mouse. Proposals are made for the first local area networks.

In 1975 the first personal computer is marketed in kit form. The Altair features 256 bytes of memory. Bill Gates, with others, writes a BASIC compiler for the machine. The next year Apple begins to market PC's, also in kit form. It includes a monitor and keyboard. The earliest RISC platforms become stable. In 1976, Queen Elizabeth goes on-line with the first royal email message.

During the next few years the personal computer explodes on the American scene. Microsoft, Apple and many smaller PC related companies form (and some die). By 1977 stores begin to sell PC's. Continuing today, companies strive to reduce the size and price of PC's while increasing capacity. Entering the fray, IBM introduces it's PC in 1981(it's actually IBM's second attempt, but the first failed miserably). Time selects the computer as its Man of the Year in 1982. Tron, a computer-generated special effects extravaganza is released the same year.