Computer History

A look back

Contents

Chapter 1

Computer

"Computer technology" and "Computer system" redirect here. For the company, see Computer Technology Limited. For other uses, see Computer (disambiguation) and Computer system (disambiguation).

A **computer** is a general purpose device that can be programmed to carry out a set of arithmetic or logical operations automatically. Since a sequence of operations can be readily changed, the computer can solve more than one kind of problem.

Conventionally, a computer consists of at least one processing element, typically a central processing unit (CPU), and some form of memory. The processing element carries out arithmetic and logic operations, and a sequencing and control unit can change the order of operations in response to stored information. Peripheral devices allow information to be retrieved from an external source, and the result of operations saved and retrieved.

Mechanical analog computers started appearing in the first century and were later used in the medieval era for astronomical calculations. In World War II, mechanical analog computers were used for specialized military applications such as calculating torpedo aiming. During this time the first electronic digital computers were developed. Originally they were the size of a large room, consuming as much power as several hundred modern personal computers (PCs).[1]

Modern computers based on integrated circuits are millions to billions of times more capable than the early machines, and occupy a fraction of the space.[2] Computers are small enough to fit into mobile devices, and mobile computers can be powered by small batteries. Personal computers in their various forms are icons of the Information Age and are generally considered as "computers". However, the embedded computers found in many devices from MP3 players to fighter aircraft and from electronic toys to industrial robots are the most numerous.

1.1 Etymology

The first known use of the word "computer" was in 1613 in a book called *The Yong Mans Gleanings* by English writer Richard Braithwait: "I haue read the truest computer of Times, and the best Arithmetician that euer breathed, and he reduceth thy dayes into a short number." It referred to a person who carried out calculations, or computations. The word continued with the same meaning until the middle of the 20th century. From the end of the 19th century the word began to take on its more familiar meaning, a machine that carries out computations.[3]

1.2 History

Main article: History of computing hardware

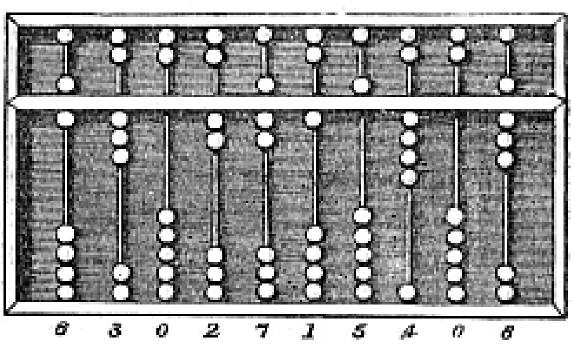
1.2.1 Pre-twentieth century

Devices have been used to aid computation for thousands of years, mostly using one-to-one correspondence with fingers. The earliest counting device was probably a form of tally stick. Later record keeping aids throughout the Fertile Crescent included calculi (clay spheres, cones, etc.) which represented counts of items, probably livestock or grains, sealed in hollow unbaked clay containers.[4][5] The use of counting rods is one example.

The abacus was initially used for arithmetic tasks. The Roman abacus was used in Babylonia as early as 2400 BC. Since then, many other forms of reckoning boards or tables have been invented. In a medieval European counting house, a checkered cloth would be placed on a table, and markers moved around on it according to certain rules, as an aid to calculating sums of money.

The Antikythera mechanism is believed to be the earliest mechanical analog "computer", according to Derek J. de

The [Ishango bone]



The Chinese Suanpan (□□) (the number represented on this abacus is 6,302,715,408)

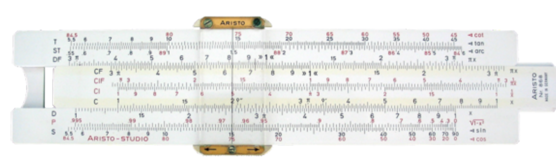
Solla Price.[6] It was designed to calculate astronomical positions. It was discovered in 1901 in the Antikythera wreck off the Greek island of Antikythera, between Kythera and Crete, and has been dated to *circa* 100 BC. Devices of a level of complexity comparable to that of the Antikythera mechanism would not reappear until a thousand years later.

The ancient Greek-designed Antikythera mechanism, dating between 150 to 100 BC, is the world's oldest analog computer.

Many mechanical aids to calculation and measurement were constructed for astronomical and navigation use. The planisphere was a star chart invented by Abū Rayhān al-Bīrūnī in the early 11th century.[7] The astrolabe was invented in the Hellenistic world in either the 1st or 2nd centuries BC and is often attributed to Hipparchus. A combination of the planisphere and dioptra, the astrolabe was effectively an analog computer capable of working out several different kinds of problems in spherical astronomy. An astrolabe incorporating a mechanical calendar computer[8][9] and gear-wheels was invented by Abi Bakr of Isfahan, Persia in 1235.[10] Abū Rayhān al-Bīrūnī invented the first mechanical geared lunisolar calendar astrolabe,[11] an early fixed-wired knowledge processing machine[12] with a gear train and gear-wheels,[13] *circa* 1000 AD.

The sector, a calculating instrument used for solving problems in proportion, trigonometry, multiplication and division, and for various functions, such as squares and cube roots, was developed in the late 16th century and found application in gunnery, surveying and navigation.

The planimeter was a manual instrument to calculate the area of a closed figure by tracing over it with a mechanical linkage.



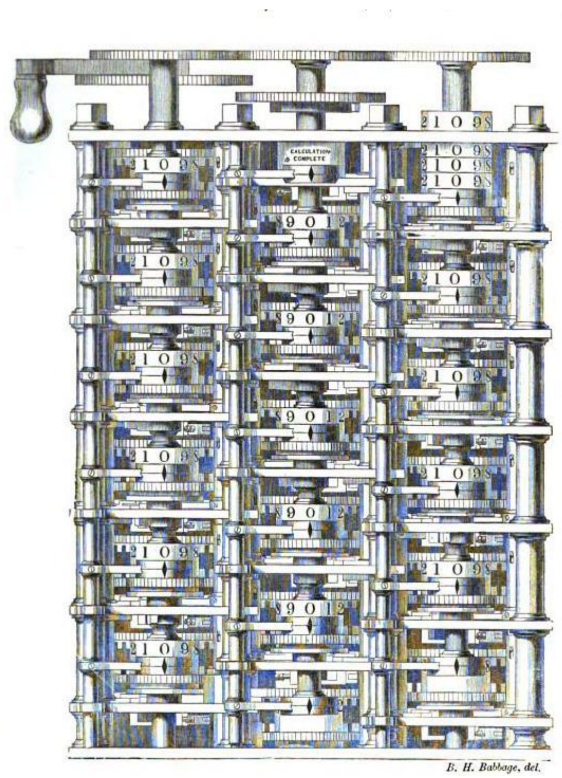
A slide rule

The slide rule was invented around 1620–1630, shortly after the publication of the concept of the logarithm. It is a hand-operated analog computer for doing multiplication and division. As slide rule development progressed, added scales provided reciprocals, squares and square roots, cubes and cube roots, as well as transcendental functions such as logarithms and exponentials, circular and hyperbolic trigonometry and other functions. Aviation is one of the few fields where slide rules are still in widespread use, particularly for solving time–distance problems in light aircraft. To save space and for ease of reading, these are typically circular devices rather than the classic linear slide rule shape. A popular example is the E6B.

In the 1770s Pierre Jaquet-Droz, a Swiss watchmaker, built a mechanical doll (automata) that could write holding a quill pen. By switching the number and order of its internal wheels different letters, and hence different messages, could be produced. In effect, it could be mechanically "programmed" to read instructions. Along with two other complex machines, the doll is at the Musée d'Art et d'Histoire of Neuchâtel, Switzerland, and still operates.[14]

The tide-predicting machine invented by Sir William Thomson in 1872 was of great utility to navigation in shallow waters. It used a system of pulleys and wires to automatically calculate predicted tide levels for a set period at a particular location.

The differential analyser, a mechanical analog computer designed to solve differential equations by integration, used wheel-and-disc mechanisms to perform the integration. In 1876 Lord Kelvin had already discussed the possible construction of such calculators, but he had been stymied by the limited output torque of the ball-and-disk integrators.[15] In a differential analyzer, the output of one integrator drove the input of the next integrator, or a graphing output. The torque amplifier was the advance that allowed these machines to work. Starting in the 1920s, Vannevar Bush and others developed mechanical differential analyzers.



A portion of Babbage's Difference engine.

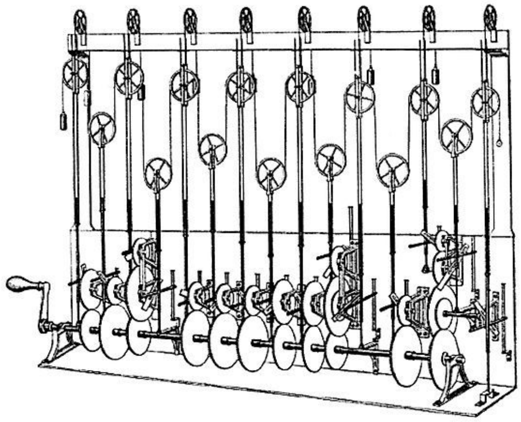
1.2.2 First general-purpose computing device

Charles Babbage, an English mechanical engineer and polymath, originated the concept of a programmable computer. Considered the "father of the computer",[16] he conceptualized and invented the first mechanical computer in the early 19th century. After working on his revolutionary difference engine, designed to aid in navigational calculations, in 1833 he realized that a much more general design, an Analytical Engine, was possible. The input of programs and data was to be provided to the machine via punched cards, a method being used at the time to direct mechanical looms such as the Jacquard loom. For output, the machine would have a printer, a curve plotter and a bell. The machine would also be able to punch numbers onto cards to be read in later. The Engine incorporated an arithmetic logic unit, control flow in the form of conditional branching and loops, and integrated memory, making it the first design for a general-purpose computer that could be described in modern terms as Turing-complete.[17][18]

The machine was about a century ahead of its time. All the parts for his machine had to be made by hand — this was a major problem for a device with thousands of parts. Eventually, the project was dissolved with the decision of the British Government to cease funding. Babbage's failure to complete the analytical engine can be chiefly attributed to difficulties not only of politics and financing, but also to his desire to develop an increasingly sophisticated computer and to move ahead faster than anyone else could follow. Nevertheless, his son, Henry Babbage, completed a simplified version of the analytical engine's computing unit (the *mill*) in 1888. He gave a successful demonstration of its use in computing tables in 1906.

1.2.3 Later analog computers

During the first half of the 20th century, many scientific computing needs were met by increasingly sophisticated analog computers, which used a direct mechan-



Sir William Thomson's third tide-predicting machine design, 1879–81

ical or electrical model of the problem as a basis for computation. However, these were not programmable and generally lacked the versatility and accuracy of modern digital computers.[19]

The first modern analog computer was a tide-predicting machine, invented by Sir William Thomson in 1872. The differential analyser, a mechanical analog computer designed to solve differential equations by integration using wheel-and-disc mechanisms, was conceptualized in 1876 by James Thomson, the brother of the more famous Lord Kelvin.[15]

The art of mechanical analog computing reached its zenith with the differential analyzer, built by H. L. Hazen and Vannevar Bush at MIT starting in 1927. This built on the mechanical integrators of James Thomson and the torque amplifiers invented by H. W. Nieman. A dozen of these devices were built before their obsolescence became obvious.

By the 1950s the success of digital electronic computers had spelled the end for most analog computing machines, but analog computers remain in use in some specialized applications such as education (control systems) and aircraft (slide rule).

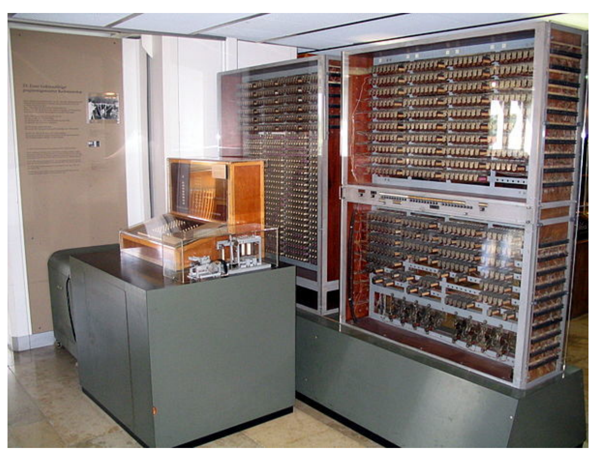
1.2.4 Digital computer development

The principle of the modern computer was first described by mathematician and pioneering computer scientist Alan Turing, who set out the idea in his seminal 1936 paper,[20] *On Computable Numbers*. Turing reformulated Kurt Gödel's 1931 results on the limits of proof and computation, replacing Gödel's universal arithmetic-based formal language with the formal and simple hypothetical devices that became known as Turing machines. He proved that some such machine would be capable of performing any conceivable mathematical computation if it were representable as an algorithm. He went on to prove that there was no solution to the *Entscheidungsproblem* by first showing that the halting problem for Turing machines is undecidable: in general, it is not possible to decide algorithmically whether a given Turing machine will ever halt.

He also introduced the notion of a 'Universal Machine' (now known as a Universal Turing machine), with the idea that such a machine could perform the tasks of any other machine, or in other words, it is provably capable of computing anything that is computable by executing a program stored on tape, allowing the machine to be programmable. Von Neumann acknowledged that the central concept of the modern computer was due to this paper.[21] Turing machines are to this day a central object of study in theory of computation. Except for the limitations imposed by their finite memory stores, modern computers are said to be Turing-complete, which is to say, they have algorithm execution capability equivalent to a universal Turing machine.

Electromechanical

By 1938 the United States Navy had developed an electromechanical analog computer small enough to use aboard a submarine. This was the Torpedo Data Computer, which used trigonometry to solve the problem of firing a torpedo at a moving target. During World War II similar devices were developed in other countries as well.



Replica of Zuse's Z3, the first fully automatic, digital (electromechanical) computer.

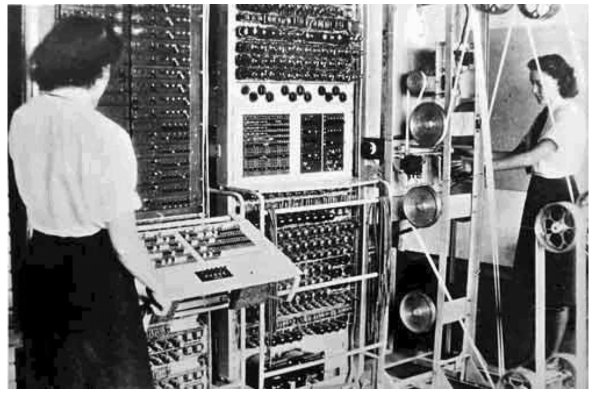
Early digital computers were electromechanical; electric switches drove mechanical relays to perform the calculation. These devices had a low operating speed and were eventually superseded by much faster all-electric computers, originally using vacuum tubes. The Z2, created by German engineer Konrad Zuse in 1939, was one of the earliest examples of an electromechanical relay computer.[22]

In 1941, Zuse followed his earlier machine up with the Z3, the world's first working electromechanical programmable, fully automatic digital computer.[23][24] The Z3 was built with 2000 relays, implementing a 22 bit word length that operated at a clock frequency of about 5–10 Hz.[25] Program code was supplied on punched film while data could be stored in 64 words of memory or supplied from the keyboard. It was quite similar to modern machines in some respects, 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.[26] The Z3 was Turing complete.[27][28]

Vacuum tubes and digital electronic circuits

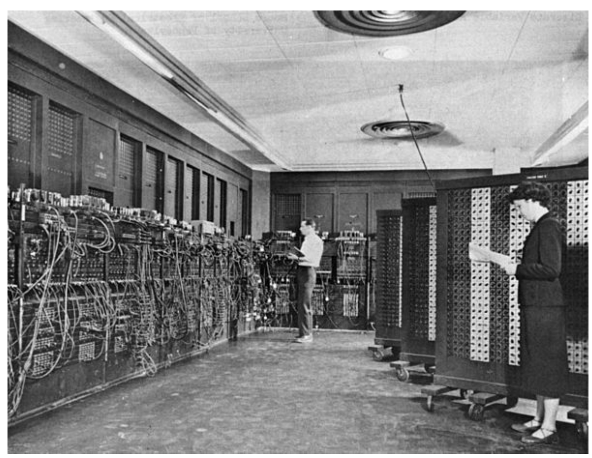
Purely electronic circuit elements soon replaced their mechanical and electromechanical equivalents, at the same time that digital calculation replaced analog. The engineer Tommy Flowers, working at the Post Office Research Station in London in the 1930s, began to explore the possible use of electronics for the telephone exchange. Experimental equipment that he built in 1934 went into operation 5 years later, converting a portion of the telephone exchange network into an electronic data processing system, using thousands of vacuum tubes.[19] In the US, John Vincent Atanasoff and Clifford E. Berry of Iowa State University developed and tested the Atanasoff–Berry Computer (ABC) in 1942,[29] the first "automatic electronic digital computer".[30] This design was also all-electronic and used about 300 vacuum tubes, with capacitors fixed in a mechanically rotating drum for memory.[31]

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 first attacked with the help of the electro-mechanical bombes. To crack the more sophisticated German Lorenz SZ 40/42 machine, used for high-level Army communications, Max Newman and his colleagues commissioned Flowers to build the Colossus.[31] He spent eleven months from early February 1943 designing and building the first Colossus.[32] After a functional test in December 1943, Colossus was shipped to Bletchley Park, where it was delivered on 18 January 1944[33] and attacked its first message on 5 February.[31]



Colossus was the first electronic digital programmable computing device, and was used to break German ciphers during World War II.

Colossus was the world's first electronic digital programmable computer.[19] It 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). Colossus Mark I contained 1500 thermionic valves (tubes), but Mark II with 2400 valves, was both 5 times faster and simpler to operate than Mark 1, greatly speeding the decoding process.[34][35]



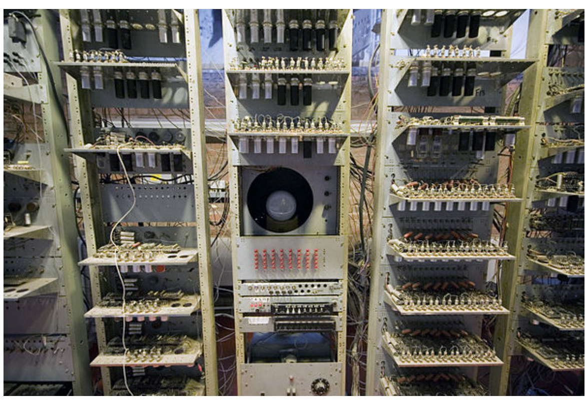
ENIAC was the first Turing-complete device, and performed ballistics trajectory calculations for the United States Army.

The US-built ENIAC[36] (Electronic Numerical Integrator and Computer) was the first electronic programmable computer built in the US. Although the ENIAC was similar to the Colossus it was much faster and more flexible. It was unambiguously a Turing-complete device and could compute any problem that would fit into its memory. Like the

Colossus, a "program" on the ENIAC was defined by the states of its patch cables and switches, a far cry from the stored program electronic machines that came later. Once a program was written, it had to be mechanically set into the machine with manual resetting of plugs and switches.

It combined the high speed of electronics with the ability to be programmed for many complex problems. It could add or subtract 5000 times a second, a thousand times faster than any other machine. It also had modules to multiply, divide, and square root. High speed memory was limited to 20 words (about 80 bytes). Built under the direction of John Mauchly and J. Presper Eckert at the University of Pennsylvania, ENIAC's development and construction lasted from 1943 to full operation at the end of 1945. The machine was huge, weighing 30 tons, using 200 kilowatts of electric power and contained over 18,000 vacuum tubes, 1,500 relays, and hundreds of thousands of resistors, capacitors, and inductors.[37]

Stored programs



A section of the Manchester Small-Scale Experimental Machine, the first stored-program computer.

Early computing machines had fixed programs. Changing its function required the re-wiring and re-structuring of the machine.[31] With the proposal of the stored-program computer this changed. A stored-program computer includes by design an instruction set and can store in memory a set of instructions (a program) that details the computation. The theoretical basis for the stored-program computer was laid by Alan Turing in his 1936 paper. In 1945 Turing joined the National Physical Laboratory and began work on developing an electronic stored-program digital computer. His 1945 report 'Proposed Electronic Calculator' was the first specification for such a device. John von Neumann at the University of Pennsylvania also circulated his *First Draft of a Report on the EDVAC* in 1945.[19]

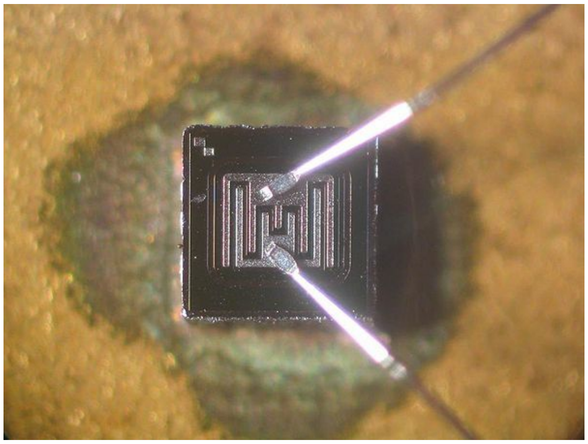
Ferranti Mark 1, c. 1951.

The Manchester Small-Scale Experimental Machine, nicknamed *Baby*, was the world's first stored-program computer. It was built at the Victoria University of Manchester by Frederic C. Williams, Tom Kilburn and Geoff Tootill, and ran its first program on 21 June 1948.[38] It was designed as a testbed for the Williams tube the first random-access digital storage device.[39] Although the computer was considered "small and primitive" by the standards of its time, it was the first working machine to contain all of the elements essential to a modern electronic computer.[40] As soon as the SSEM had demonstrated the feasibility of its design, a project was initiated at the university to develop it into a more usable computer, the Manchester Mark 1.

The Mark 1 in turn quickly became the prototype for the Ferranti Mark 1, the world's first commercially available general-purpose computer.[41] Built by Ferranti, it was delivered to the University of Manchester in February 1951. At least seven of these later machines were delivered between 1953 and 1957, one of them to Shell labs in Amsterdam.[42] In October 1947, the directors of British catering company J. Lyons & Company decided to take an active role in promoting the commercial development of computers. The LEO I computer became operational in April 1951 [43] and ran the world's first regular routine office computer job.

Transistors

The bipolar transistor was invented in 1947. From 1955 onwards transistors replaced vacuum tubes in computer de-



A bipolar junction transistor

signs, giving rise to the "second generation" of computers. Compared to vacuum tubes, transistors have many advantages: they are smaller, and require less power than vacuum tubes, so give off less heat. Silicon junction transistors were much more reliable than vacuum tubes and had longer, indefinite, service life. Transistorized computers could contain tens of thousands of binary logic circuits in a relatively compact space.

At the University of Manchester, a team under the leadership of Tom Kilburn designed and built a machine using the newly developed transistors instead of valves.[44] Their first transistorised computer and the first in the world, was operational by 1953, and a second version was completed there in April 1955. However, the machine did make use of valves to generate its 125 kHz clock waveforms and in the circuitry to read and write on its magnetic drum memory, so it was not the first completely transistorized computer. That distinction goes to the Harwell CADET of 1955,[45] built by the electronics division of the Atomic Energy Research Establishment at Harwell.[46][47]

Integrated circuits

The next great advance in computing power came with the advent of the integrated circuit. The idea of the integrated circuit was first conceived by a radar scientist working for the Royal Radar Establishment of the Ministry of Defence, Geoffrey W.A. Dummer. Dummer presented the first public description of an integrated circuit at the Symposium on Progress in Quality Electronic Components in Washington, D.C. on 7 May 1952.[48]

The first practical ICs were invented by Jack Kilby at Texas Instruments and Robert Noyce at Fairchild Semiconductor.[49] Kilby recorded his initial ideas concerning the integrated circuit in July 1958, successfully demonstrating the first working integrated example on 12 September 1958.[50] In his patent application of 6 February 1959, Kilby described his new device as "a body of semiconductor material ... wherein all the components of the electronic circuit are completely integrated".[51][52] Noyce also came up with his own idea of an integrated circuit half a year later than Kilby.[53] His chip solved many practical problems that Kilby's had not. Produced at Fairchild Semiconductor, it was made of silicon, whereas Kilby's chip was made of germanium.

This new development heralded an explosion in the commercial and personal use of computers and led to the invention of the microprocessor. While the subject of exactly which device was the first microprocessor is contentious, partly due to lack of agreement on the exact definition of the term "microprocessor", it is largely undisputed that the first single-chip microprocessor was the Intel 4004,[54] designed and realized by Ted Hoff, Federico Faggin, and Stanley Mazor at Intel.[55]

1.2.5 Mobile computers become dominant

With the continued miniaturization of computing resources, and advancements in portable battery life, portable computers grew in popularity in the 2000s.[56] The same developments that spurred the growth of laptop computers and other portable computers allowed manufacturers to integrate computing resources into cellular phones. These so-called smartphones and tablets run on a variety of operating systems and have become the dominant computing device on the market, with manufacturers reporting having shipped an estimated 237 million devices in 2Q 2013.[57]

1.3 Programs

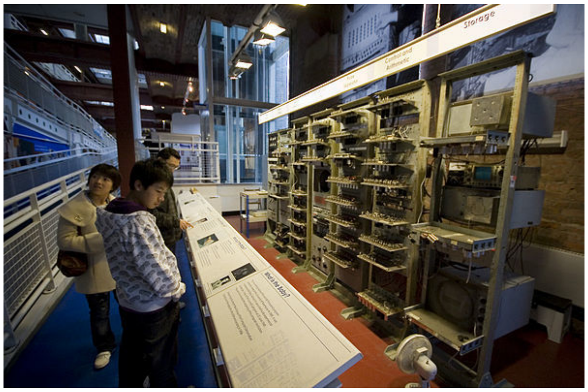
The defining feature of modern computers which distinguishes them from all other machines is that they can be programmed. That is to say that some type of instructions (the program) can be given to the computer, and it will process them. Modern computers based on the von Neumann architecture often have machine code in the form of an imperative programming language.

In practical terms, a computer program may be just a few instructions or extend to many millions of instructions, as do the programs for word processors and web browsers for example. A typical modern computer can execute billions of instructions per second (gigaflops) and rarely makes a mistake over many years of operation. Large computer programs consisting of several million instructions may take teams of programmers years to write, and due to the complexity of the task almost certainly contain errors.

1.3.1 Stored program architecture

Main articles: Computer program and Computer programming

This section applies to most common RAM machine-based



Replica of the Small-Scale Experimental Machine (SSEM), the world's first stored-program computer, at the Museum of Science and Industry in Manchester, England

computers.

In most cases, computer instructions are simple: add one number to another, move some data from one location to another, send a message to some external device, etc. These instructions are read from the computer's memory and are generally carried out (executed) in the order they were given. However, there are usually specialized instructions to tell the computer to jump ahead or backwards to some other place in the program and to carry on executing from there. These are called "jump" instructions (or branches). Furthermore, jump instructions may be made to happen conditionally so that different sequences of instructions may be used depending on the result of some previous calculation or some external event. Many computers directly support subroutines by providing a type of jump that "remembers" the location it jumped from and another instruction to return to the instruction following that jump instruction.

Program execution might be likened to reading a book. While a person will normally read each word and line in sequence, they may at times jump back to an earlier place in the text or skip sections that are not of interest. Similarly, a computer may sometimes go back and repeat the instructions in some section of the program over and over again until some internal condition is met. This is called the flow of control within the program and it is what allows the computer to perform tasks repeatedly without human intervention.

Comparatively, a person using a pocket calculator can perform a basic arithmetic operation such as adding two numbers with just a few button presses. But to add together all of the numbers from 1 to 1,000 would take thousands of button presses and a lot of time, with a near certainty of making a mistake. On the other hand, a computer may be programmed to do this with just a few simple instructions. The following example is written in the MIPS assembly language:

begin: addi $8, $0, 0 # initialize sum to 0 addi $9, $0, 1 # set first number to add = 1 loop: slti $10, $9, 1000 # check if the number is less than 1000 beq $10, $0, finish # if odd number is greater than n then exit add $8, $8, $9 # update sum addi $9, $9, 1 # get next number j loop # repeat the summing process finish: add $2, $8, $0 # put sum in output register

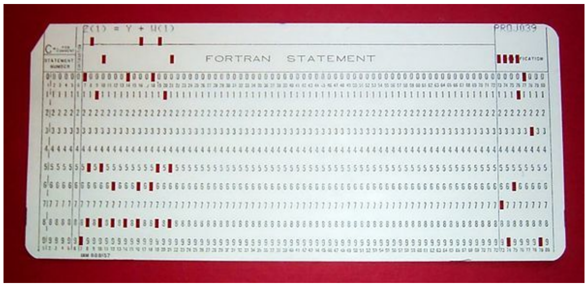
Once told to run this program, the computer will perform the repetitive addition task without further human intervention. It will almost never make a mistake and a modern PC can complete the task in a fraction of a second.

1.3.2 Machine code

In most computers, individual instructions are stored as machine code with each instruction being given a unique number (its operation code or opcode for short). The command to add two numbers together would have one opcode; the command to multiply them would have a different opcode, and so on. The simplest computers are able to perform any of a handful of different instructions; the more complex computers have several hundred to choose from, each with a unique numerical code. Since the computer's memory is able to store numbers, it can also store the instruction codes. This leads to the important fact that entire programs (which are just lists of these instructions) can be represented as lists of numbers and can themselves be manipulated inside the computer in the same way as numeric data. The fundamental concept of storing programs in the computer's memory alongside the data they operate on is the crux of the von Neumann, or stored program, architecture. In some cases, a computer might store some or all of its program in memory that is kept separate from the data it operates on. This is called the Harvard architecture after the Harvard Mark I computer. Modern von Neumann computers display some traits of the Harvard architecture in their designs, such as in CPU caches.

While it is possible to write computer programs as long lists of numbers (machine language) and while this technique was used with many early computers,[58] it is extremely tedious and potentially error-prone to do so in practice, especially for complicated programs. Instead, each basic instruction can be given a short name that is indicative of its function and easy to remember – a mnemonic such as

ADD, SUB, MULT or JUMP. These mnemonics are collectively known as a computer's assembly language. Converting programs written in assembly language into something the computer can actually understand (machine language) is usually done by a computer program called an assembler.



A 1970s punched card containing one line from a FORTRAN program. The card reads: "Z(1) = Y + W(1)" and is labeled "PROJ039" for identification purposes.

1.3.3 Programming language

Main article: Programming language

Programming languages provide various ways of specifying programs for computers to run. Unlike natural languages, programming languages are designed to permit no ambiguity and to be concise. They are purely written languages and are often difficult to read aloud. They are generally either translated into machine code by a compiler or an assembler before being run, or translated directly at run time by an interpreter. Sometimes programs are executed by a hybrid method of the two techniques.

Low-level languages

Main article: Low-level programming language

Machine languages and the assembly languages that represent them (collectively termed *low-level programming languages*) tend to be unique to a particular type of computer. For instance, an ARM architecture computer (such as may be found in a PDA or a hand-held videogame) cannot understand the machine language of an Intel Pentium or the AMD Athlon 64 computer that might be in a PC.[59]

High-level languages/Third Generation Language

Main article: High-level programming language

Though considerably easier than in machine language, writing long programs in assembly language is often difficult and is also error prone. Therefore, most practical programs are written in more abstract high-level programming languages that are able to express the needs of the programmer more conveniently (and thereby help reduce programmer error). High level languages are usually "compiled" into machine language (or sometimes into assembly language and then into machine language) using another computer program called a compiler.[60] High level languages are less related to the workings of the target computer than assembly language, and more related to the language and structure of the problem(s) to be solved by the final program. It is therefore often possible to use different compilers to translate the same high level language program into the machine language of many different types of computer. This is part of the means by which software like video games may be made available for different computer architectures such as personal computers and various video game consoles.

1.3.4 Fourth Generation Languages

These 4G languages are less procedural than 3G languages. The benefit of 4GL is that it provides ways to obtain information without requiring the direct help of a programmer. Example of 4GL is SQL.

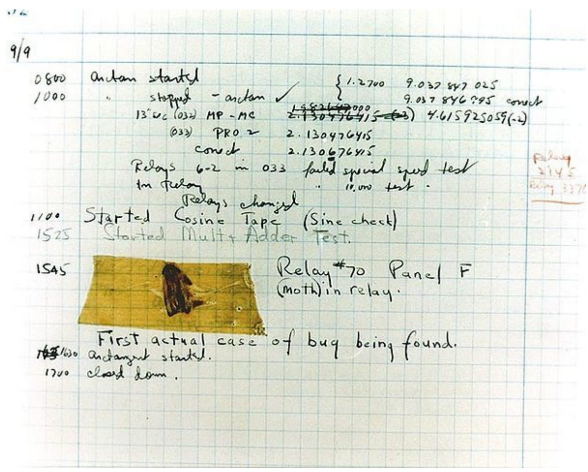
1.3.5 Program design

Program design of small programs is relatively simple and involves the analysis of the problem, collection of inputs, using the programming constructs within languages, devising or using established procedures and algorithms, providing data for output devices and solutions to the problem as applicable. As problems become larger and more complex, features such as subprograms, modules, formal documentation, and new paradigms such as object-oriented programming are encountered. Large programs involving thousands of line of code and more require formal software methodologies. The task of developing large software systems presents a significant intellectual challenge. Producing software with an acceptably high reliability within a predictable schedule and budget has historically been difficult; the academic and professional discipline of software engineering concentrates specifically on this challenge.

1.3.6 Bugs

Main article: Software bug

Errors in computer programs are called "bugs". They may be benign and not affect the usefulness of the program, or have only subtle effects. But in some cases, they may



The actual first computer bug, a moth found trapped on a relay of the Harvard Mark II computer

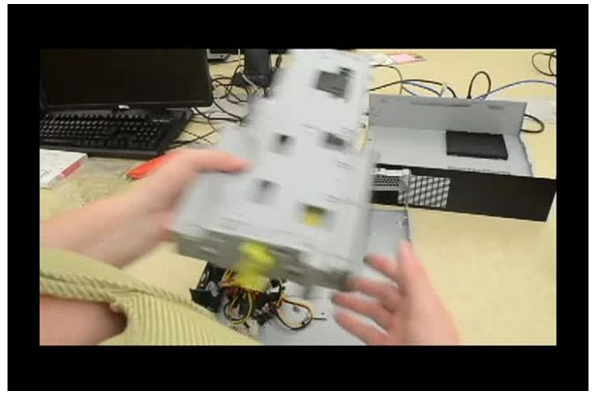
cause the program or the entire system to "hang", becoming unresponsive to input such as mouse clicks or keystrokes, to completely fail, or to crash. Otherwise benign bugs may sometimes be harnessed for malicious intent by an unscrupulous user writing an exploit, code designed to take advantage of a bug and disrupt a computer's proper execution. Bugs are usually not the fault of the computer. Since computers merely execute the instructions they are given, bugs are nearly always the result of programmer error or an oversight made in the program's design.[61]

Admiral Grace Hopper, an American computer scientist and developer of the first compiler, is credited for having first used the term "bugs" in computing after a dead moth was found shorting a relay in the Harvard Mark II computer in September 1947.[62]

1.4 Components

Main articles: Central processing unit and Microprocessor
A general purpose computer has four main components: the arithmetic logic unit (ALU), the control unit, the memory, and the input and output devices (collectively termed I/O). These parts are interconnected by buses, often made of groups of wires.

Inside each of these parts are thousands to trillions of small electrical circuits which can be turned off or on by means of an electronic switch. Each circuit represents a bit (binary digit) of information so that when the circuit is on it represents a "1", and when off it represents a "0" (in positive logic representation). The circuits are arranged in logic gates so that one or more of the circuits may control the state of one or more of the other circuits.



Video demonstrating the standard components of a "slimline" computer

1.4.1 Control unit

Main articles: CPU design and Control unit
The control unit (often called a control system or central controller) manages the computer's various components; it reads and interprets (decodes) the program instructions, transforming them into control signals that activate other parts of the computer.[63] Control systems in advanced computers may change the order of execution of some instructions to improve performance.

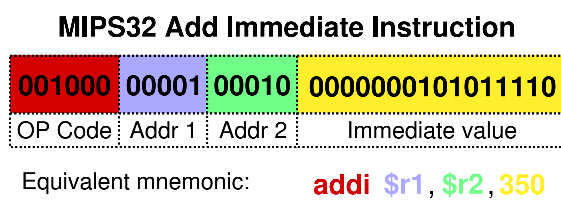


Diagram showing how a particular MIPS architecture instruction would be decoded by the control system

A key component common to all CPUs is the program counter, a special memory cell (a register) that keeps track of which location in memory the next instruction is to be read from.[64]

The control system's function is as follows—note that this is a simplified description, and some of these steps may be performed concurrently or in a different order depending on the type of CPU:

1. Read the code for the next instruction from the cell indicated by the program counter.

2. Decode the numerical code for the instruction into a set of commands or signals for each of the other systems.

3. Increment the program counter so it points to the next instruction.

4. Read whatever data the instruction requires from cells in memory (or perhaps from an input device). The location of this required data is typically stored within the instruction code.

5. Provide the necessary data to an ALU or register.

6. If the instruction requires an ALU or specialized hardware to complete, instruct the hardware to perform the requested operation.

7. Write the result from the ALU back to a memory location or to a register or perhaps an output device.

8. Jump back to step (1).

Since the program counter is (conceptually) just another set of memory cells, it can be changed by calculations done in the ALU. Adding 100 to the program counter would cause the next instruction to be read from a place 100 locations further down the program. Instructions that modify the program counter are often known as "jumps" and allow for loops (instructions that are repeated by the computer) and often conditional instruction execution (both examples of control flow).

The sequence of operations that the control unit goes through to process an instruction is in itself like a short computer program, and indeed, in some more complex CPU designs, there is another yet smaller computer called a microsequencer, which runs a microcode program that causes all of these events to happen.

1.4.2 Central processing unit (CPU)

The control unit, ALU, and registers are collectively known as a central processing unit (CPU). Early CPUs were composed of many separate components but since the mid-1970s CPUs have typically been constructed on a single integrated circuit called a *microprocessor*.

1.4.3 Arithmetic logic unit (ALU)

Main article: Arithmetic logic unit

The ALU is capable of performing two classes of operations: arithmetic and logic.[65]

The set of arithmetic operations that a particular ALU supports may be limited to addition and subtraction, or might include multiplication, division, trigonometry functions such as sine, cosine, etc., and square roots. Some can only operate on whole numbers (integers) whilst others use floating point to represent real numbers, albeit with limited precision. However, any computer that is capable of performing just the simplest operations can be programmed to break down the more complex operations into simple steps that it can perform. Therefore, any computer can be programmed to perform any arithmetic operation—although it will take more time to do so if its ALU does not directly support the operation. An ALU may also compare numbers and return boolean truth values (true or false) depending on whether one is equal to, greater than or less than the other ("is 64 greater than 65?").

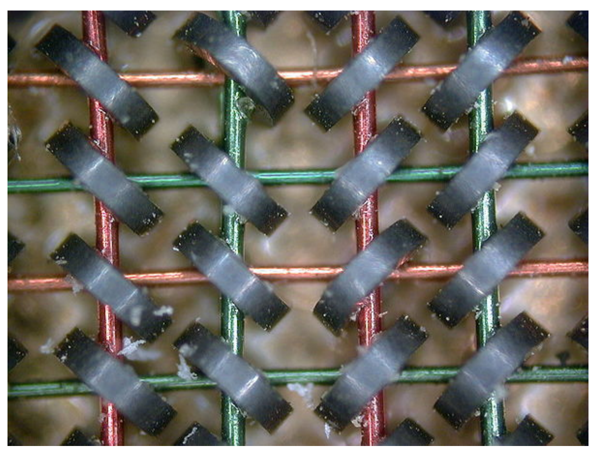
Logic operations involve Boolean logic: AND, OR, XOR, and NOT. These can be useful for creating complicated conditional statements and processing boolean logic.

Superscalar computers may contain multiple ALUs, allowing them to process several instructions simultaneously.[66] Graphics processors and computers with SIMD and MIMD features often contain ALUs that can perform arithmetic on vectors and matrices.

1.4.4 Memory

Main article: Computer data storage

A computer's memory can be viewed as a list of cells into



Magnetic core memory was the computer memory of choice throughout the 1960s, until it was replaced by semiconductor memory.

which numbers can be placed or read. Each cell has a numbered "address" and can store a single number. The computer can be instructed to "put the number 123 into the cell numbered 1357" or to "add the number that is in cell 1357 to the number that is in cell 2468 and put the answer into cell 1595." The information stored in memory may represent practically anything. Letters, numbers, even computer instructions can be placed into memory with equal ease. Since the CPU does not differentiate between different types of information, it is the software's responsibility to give significance to what the memory sees as nothing but a series of numbers.

In almost all modern computers, each memory cell is set up to store binary numbers in groups of eight bits (called a byte). Each byte is able to represent 256 different numbers ($2^8 = 256$); either from 0 to 255 or −128 to +127. To store larger numbers, several consecutive bytes may be used (typically, two, four or eight). When negative numbers are required, they are usually stored in two's complement notation. Other arrangements are possible, but are usually not seen outside of specialized applications or historical contexts. A computer can store any kind of information in memory if it can be represented numerically. Modern computers have billions or even trillions of bytes of memory.

The CPU contains a special set of memory cells called registers that can be read and written to much more rapidly than the main memory area. There are typically between two and one hundred registers depending on the type of CPU. Registers are used for the most frequently needed data items to avoid having to access main memory every time data is needed. As data is constantly being worked on, reducing the need to access main memory (which is often slow compared to the ALU and control units) greatly increases the computer's speed.

Computer main memory comes in two principal varieties:

- random-access memory or RAM
- read-only memory or ROM

RAM can be read and written to anytime the CPU commands it, but ROM is preloaded with data and software that never changes, therefore the CPU can only read from it. ROM is typically used to store the computer's initial start-up instructions. In general, the contents of RAM are erased when the power to the computer is turned off, but ROM retains its data indefinitely. In a PC, the ROM contains a specialized program called the BIOS that orchestrates loading the computer's operating system from the hard disk drive into RAM whenever the computer is turned on or reset. In embedded computers, which frequently do not have disk drives, all of the required software may be stored in ROM. Software stored in ROM is often called firmware, because it is notionally more like hardware than software. Flash memory blurs the distinction between ROM and RAM, as it retains its data when turned off but is also rewritable. It is typically much slower than conventional ROM and RAM however, so its use is restricted to applications where high speed is unnecessary.[67]

In more sophisticated computers there may be one or more RAM cache memories, which are slower than registers but faster than main memory. Generally computers with this sort of cache are designed to move frequently needed data into the cache automatically, often without the need for any intervention on the programmer's part.

1.4.5 Input/output (I/O)

Main article: Input/output

I/O is the means by which a computer exchanges information with the outside world.[68] Devices that provide input or output to the computer are called peripherals.[69] On a typical personal computer, peripherals include input devices like the keyboard and mouse, and output devices such as the display and printer. Hard disk drives, floppy disk drives and optical disc drives serve as both input and output devices. Computer networking is another form of I/O.

Hard disk drives are common storage devices used with computers.

I/O devices are often complex computers in their own right, with their own CPU and memory. A graphics processing unit might contain fifty or more tiny computers that perform the calculations necessary to display 3D graphics. Modern desktop computers contain many smaller computers that assist the main CPU in performing I/O.

1.4.6 Multitasking

Main article: Computer multitasking

While a computer may be viewed as running one gigantic program stored in its main memory, in some systems it is necessary to give the appearance of running several programs simultaneously. This is achieved by multitasking i.e. having the computer switch rapidly between running each program in turn.[70]

One means by which this is done is with a special signal called an interrupt, which can periodically cause the computer to stop executing instructions where it was and do something else instead. By remembering where it was executing prior to the interrupt, the computer can return to that task later. If several programs are running “at the same time”. then the interrupt generator might be causing several hundred interrupts per second, causing a program switch each time. Since modern computers typically execute instructions several orders of magnitude faster than human perception, it may appear that many programs are running at the same time even though only one is ever executing in any given instant. This method of multitasking is sometimes termed “time-sharing” since each program is allocated a “slice” of time in turn.[71]

Before the era of cheap computers, the principal use for multitasking was to allow many people to share the same computer.

Seemingly, multitasking would cause a computer that is switching between several programs to run more slowly, in direct proportion to the number of programs it is running, but most programs spend much of their time waiting for slow input/output devices to complete their tasks. If a program is waiting for the user to click on the mouse or press a key on the keyboard, then it will not take a “time slice” until the event it is waiting for has occurred. This frees up time for other programs to execute so that many programs may be run simultaneously without unacceptable speed loss.

1.4.7 Multiprocessing

Main article: Multiprocessing

Some computers are designed to distribute their work

Cray designed many supercomputers that used multiprocessing heavily.

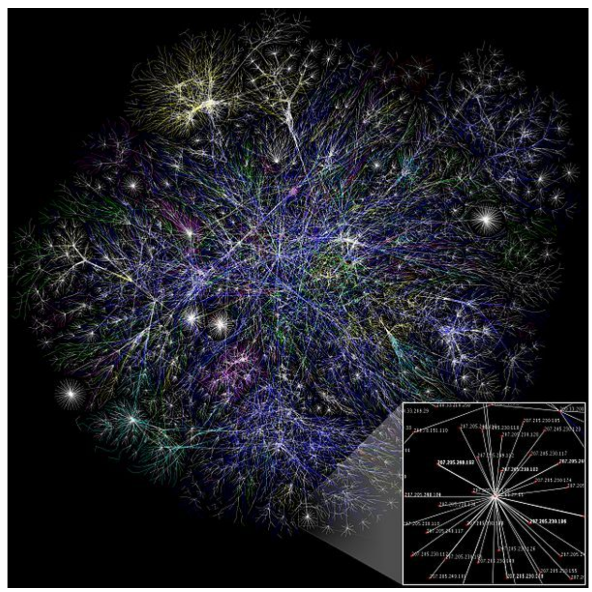
across several CPUs in a multiprocessing configuration, a technique once employed only in large and powerful machines such as supercomputers, mainframe computers and servers. Multiprocessor and multi-core (multiple CPUs on a single integrated circuit) personal and laptop computers are now widely available, and are being increasingly used in lower-end markets as a result.

Supercomputers in particular often have highly unique architectures that differ significantly from the basic stored-program architecture and from general purpose computers.[72] They often feature thousands of CPUs, customized high-speed interconnects, and specialized computing hardware. Such designs tend to be useful only for specialized tasks due to the large scale of program organization required to successfully utilize most of the available resources at once. Supercomputers usually see usage in large-scale simulation, graphics rendering, and cryptography applications, as well as with other so-called "embarrassingly parallel" tasks.

1.5 Networking and the Internet

Main articles: Computer networking and Internet

Computers have been used to coordinate information be-



Visualization of a portion of the routes on the Internet

tween multiple locations since the 1950s. The U.S. military’s SAGE system was the first large-scale example of such a system, which led to a number of special-purpose commercial systems such as Sabre.[73]

In the 1970s, computer engineers at research institutions throughout the United States began to link their computers together using telecommunications technology. The effort was funded by ARPA (now DARPA), and the computer network that resulted was called the ARPANET.[74] The technologies that made the Arpanet possible spread and evolved.

In time, the network spread beyond academic and military institutions and became known as the Internet. The emergence of networking involved a redefinition of the nature and boundaries of the computer. Computer operating systems and applications were modified to include the ability to define and access the resources of other computers on the network, such as peripheral devices, stored information, and the like, as extensions of the resources of an individual computer. Initially these facilities were available primarily to people working in high-tech environments, but in the 1990s the spread of applications like e-mail and the World Wide Web, combined with the development of cheap, fast networking technologies like Ethernet and ADSL saw computer networking become almost ubiquitous. In fact, the number of computers that are networked is growing phenomenally. A very large proportion of personal computers regularly connect to the Internet to communicate and receive information. “Wireless” networking, often utilizing mobile phone networks, has meant networking is becoming increasingly ubiquitous even in mobile computing environments.

1.5.1 Computer architecture paradigms

There are many types of computer architectures:

- Quantum computer vs. Chemical computer
- Scalar processor vs. Vector processor
- Non-Uniform Memory Access (NUMA) computers
- Register machine vs. Stack machine
- Harvard architecture vs. von Neumann architecture
- Cellular architecture

Of all these abstract machines, a quantum computer holds the most promise for revolutionizing computing.[75]

Logic gates are a common abstraction which can apply to most of the above digital or analog paradigms.

The ability to store and execute lists of instructions called programs makes computers extremely versatile, distinguishing them from calculators. The Church–Turing thesis is a mathematical statement of this versatility: any computer with a minimum capability (being Turing-complete) is, in principle, capable of performing the same tasks that any other computer can perform. Therefore, any type of computer (netbook, supercomputer, cellular automaton, etc.) is able to perform the same computational tasks, given enough time and storage capacity.

1.6 Misconceptions

Main articles: Human computer and Harvard Computers

A computer does not need to be electronic, nor even have

Women as computers *in NACA High Speed Flight Station “Computer Room”*

a processor, nor RAM, nor even a hard disk. While popular usage of the word “computer” is synonymous with a personal electronic computer, the modern[76] definition of a computer is literally: "*A device that computes*, especially a programmable [usually] electronic machine that performs high-speed mathematical or logical operations or that assembles, stores, correlates, or otherwise processes information.”[77] Any device which *processes information* qualifies as a computer, especially if the processing is purposeful.

1.6.1 Unconventional computing

Main article: Unconventional computing

Historically, computers evolved from mechanical computers and eventually from vacuum tubes to transistors. However, conceptually computational systems as flexible as a personal computer can be built out of almost anything. For example, a computer can be made out of billiard balls (billiard ball computer); an often quoted example. More realistically, modern computers are made out of transistors made of photolithographed semiconductors.

1.7 Future

There is active research to make computers out of many promising new types of technology, such as optical computers, DNA computers, neural computers, and quantum computers. Most computers are universal, and are able to calculate any computable function, and are limited only by their memory capacity and operating speed. However different designs of computers can give very different performance for particular problems; for example quantum computers can potentially break some modern encryption algorithms (by quantum factoring) very quickly.

1.8 Further topics

- Glossary of computers

1.8.1 Artificial intelligence

A computer will solve problems in exactly the way it is programmed to, without regard to efficiency, alternative solutions, possible shortcuts, or possible errors in the code. Computer programs that learn and adapt are part of the emerging field of artificial intelligence and machine learning.

1.9 Hardware

Main articles: Computer hardware and Personal computer hardware

The term *hardware* covers all of those parts of a computer that are tangible objects. Circuits, displays, power supplies, cables, keyboards, printers and mice are all hardware.

1.9.1 History of computing hardware

Main article: History of computing hardware

1.9.2 Other hardware topics

1.10 Software

Main article: Computer software

Software refers to parts of the computer which do not have a material form, such as programs, data, protocols, etc. When software is stored in hardware that cannot easily be modified (such as BIOS ROM in an IBM PC compatible), it is sometimes called “firmware”.

1.11 Languages

There are thousands of different programming languages—some intended to be general purpose, others useful only for highly specialized applications.

1.11.1 Firmware

Firmware is the technology which has the combination of both hardware and software such as BIOS chip inside a computer. This chip (hardware) is located on the motherboard and has the BIOS set up (software) stored in it.

1.12 Types of computers

Computers are typically classified based on their uses:

1.12.1 Based on uses

- Analog computer
- Digital computer
- Hybrid computer

1.12.2 Based on sizes

- Micro computer
- Personal computer
- Mini Computer
- Mainframe computer
- Super computer

1.13 Input Devices

When unprocessed data is sent to the computer with the help of input devices, the data is processed and sent to output devices. The input devices may be hand-operated or automated. The act of processing is mainly regulated by the CPU. Some examples of hand-operated input devices are:

- Overlay keyboard
- Trackball
- Joystick

- Digital camera
- Microphone
- Touchscreen
- Digital video
- Image scanner
- Graphics tablet
- Computer keyboard
- Mouse

1.14 Output Devices

The means through which computer gives output are known as output devices. Some examples of output devices are:

- Computer monitor
- Printer
- Projector
- Sound card
- PC speaker
- Video card

1.15 Professions and organizations

As the use of computers has spread throughout society, there are an increasing number of careers involving computers.

The need for computers to work well together and to be able to exchange information has spawned the need for many standards organizations, clubs and societies of both a formal and informal nature.

1.16 See also

- Computability theory
- Computer insecurity
- Computer security
- List of computer term etymologies
- List of fictional computers
- Pulse computation
- TOP500 (list of most powerful computers)

1.17 Notes

[1] In 1946, ENIAC required an estimated 174 kW. By comparison, a modern laptop computer may use around 30 W; nearly six thousand times less. "Approximate Desktop & Notebook Power Usage". University of Pennsylvania. Retrieved 20 June 2009.

[2] Early computers such as Colossus and ENIAC were able to process between 5 and 100 operations per second. A modern "commodity" microprocessor (as of 2007) can process billions of operations per second, and many of these operations are more complicated and useful than early computer operations. "Intel Core2 Duo Mobile Processor: Features". Intel Corporation. Retrieved 20 June 2009.

[3] "computer, *n*.". Oxford English Dictionary (2 ed.). Oxford University Press. 1989. Retrieved 10 April 2009.

[4] According to Schmandt-Besserat 1981, these clay containers contained tokens, the total of which were the count of objects being transferred. The containers thus served as something of a bill of lading or an accounts book. In order to avoid breaking open the containers, first, clay impressions of the tokens were placed on the outside of the containers, for the count; the shapes of the impressions were abstracted into stylized marks; finally, the abstract marks were systematically used as numerals; these numerals were finally formalized as numbers. Eventually (Schmandt-Besserat estimates it took 4000 years) the marks on the outside of the containers were all that were needed to convey the count, and the clay containers evolved into clay tablets with marks for the count. Archived 30 January 2012 at the Wayback Machine.

[5] Robson, Eleanor (2008), *Mathematics in Ancient Iraq*, ISBN 978-0-691-09182-2. p.5: calculi were in use in Iraq for primitive accounting systems as early as 3200–3000 BCE, with commodity-specific counting representation systems. Balanced accounting was in use by 3000–2350 BCE, and a sexagesimal number system was in use 2350–2000 BCE.

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[20] Proceedings of the London Mathematical Society

[21] “von Neumann ... firmly emphasized to me, and to others I am sure, that the fundamental conception is owing to Turing—insofar as not anticipated by Babbage, Lovelace and others.” Letter by Stanley Frankel to Brian Randell, 1972, quoted in Jack Copeland (2004) *The Essential Turing*, p22.

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[56] Global notebook shipments finally overtake desktops | Ars Technica

[57] Archived 26 June 2014 at the Wayback Machine.

[58] Even some later computers were commonly programmed directly in machine code. Some minicomputers like the DEC PDP-8 could be programmed directly from a panel of switches. However, this method was usually used only as part of the booting process. Most modern computers boot entirely automatically by reading a boot program from some non-volatile memory.

[59] However, there is sometimes some form of machine language compatibility between different computers. An x86-64 compatible microprocessor like the AMD Athlon 64 is able to run most of the same programs that an Intel Core 2 microprocessor can, as well as programs designed for earlier microprocessors like the Intel Pentiums and Intel 80486. This contrasts with very early commercial computers, which were often one-of-a-kind and totally incompatible with other computers.

[60] High level languages are also often interpreted rather than compiled. Interpreted languages are translated into machine code on the fly, while running, by another program called an interpreter.

[61] It is not universally true that bugs are solely due to programmer oversight. Computer hardware may fail or may itself have a fundamental problem that produces unexpected results in certain situations. For instance, the Pentium FDIV bug caused some Intel microprocessors in the early 1990s to produce inaccurate results for certain floating point division operations. This was caused by a flaw in the microprocessor design and resulted in a partial recall of the affected devices.

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[63] The control unit's role in interpreting instructions has varied somewhat in the past. Although the control unit is solely responsible for instruction interpretation in most modern computers, this is not always the case. Some computers have instructions that are partially interpreted by the control unit with further interpretation performed by another device. For example, EDVAC, one of the earliest stored-program computers, used a central control unit that only interpreted four instructions. All of the arithmetic-related instructions were passed on to its arithmetic unit and further decoded there.

[64] Instructions often occupy more than one memory address, therefore the program counter usually increases by the number of memory locations required to store one instruction.

[65] David J. Eck (2000). *The Most Complex Machine: A Survey of Computers and Computing*. A K Peters, Ltd. p. 54. ISBN 978-1-56881-128-4.

[66] Erricos John Kontoghiorghes (2006). *Handbook of Parallel Computing and Statistics*. CRC Press. p. 45. ISBN 978-0-8247-4067-2.

[67] Flash memory also may only be rewritten a limited number of times before wearing out, making it less useful for heavy random access usage. (Verma & Mielke 1988)

[68] Donald Eadie (1968). *Introduction to the Basic Computer*. Prentice-Hall. p. 12.

[69] Arpad Barna; Dan I. Porat (1976). *Introduction to Microcomputers and the Microprocessors*. Wiley. p. 85. ISBN 978-0-471-05051-3.

[70] Jerry Peek; Grace Todino; John Strang (2002). *Learning the UNIX Operating System: A Concise Guide for the New User*. O'Reilly. p. 130. ISBN 978-0-596-00261-9.

[71] Gillian M. Davis (2002). *Noise Reduction in Speech Applications*. CRC Press. p. 111. ISBN 978-0-8493-0949-6.

[72] However, it is also very common to construct supercomputers out of many pieces of cheap commodity hardware; usually individual computers connected by networks. These so-called computer clusters can often provide supercomputer

performance at a much lower cost than customized designs. While custom architectures are still used for most of the most powerful supercomputers, there has been a proliferation of cluster computers in recent years. (TOP500 2006)

[73] Agatha C. Hughes (2000). *Systems, Experts, and Computers*. MIT Press. p. 161. ISBN 978-0-262-08285-3. The experience of SAGE helped make possible the first truly large-scale commercial real-time network: the SABRE computerized airline reservations system...

[74] "A Brief History of the Internet". Internet Society. Retrieved 20 September 2008.

[75] "Computer architecture: fundamentals and principles of computer design" by Joseph D. Dumas 2006. page 340.

[76] According to the *Shorter Oxford English Dictionary* (6th ed, 2007), the word *computer* dates back to the mid 17th century, when it referred to "A person who makes calculations; specifically a person employed for this in an observatory etc."

[77] "Definition of computer". Thefreedictionary.com. Retrieved 29 January 2012.

[78] Most major 64-bit instruction set architectures are extensions of earlier designs. All of the architectures listed in this table, except for Alpha, existed in 32-bit forms before their 64-bit incarnations were introduced.

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1.19 External links

- Warhol & The Computer

Wikiversity has a quiz on this article

Chapter 2

Analog computer

A page from the Bombardier's Information File *(BIF) that describes the components and controls of the Norden bombsight. The* ***Norden bombsight*** *was a highly sophisticated optical/mechanical analog computer used by the United States Army Air Force during World War II, the Korean War, and the Vietnam War to aid the pilot of a bomber aircraft in dropping bombs accurately.*

An **analog computer** is a form of computer that uses the continuously changeable aspects of physical phenomena such as electrical, mechanical, or hydraulic quantities to model the problem being solved. In contrast, digital computers represent varying quantities symbolically, as their numerical values change. As an analog computer does not use discrete values, but rather continuous values, processes cannot be reliably repeated with exact equivalence, as they can with Turing machines. Analog computers do not suffer from the quantization noise inherent in digital computers, but are limited instead by analog noise.

Analog computers were widely used in scientific and industrial applications where digital computers of the time lacked sufficient performance. Analog computers can have a very wide range of complexity. Slide rules and nomographs are the simplest, while naval gunfire control computers and large hybrid digital/analog computers were among the most complicated.[1] Systems for process control and protective relays used analog computation to perform control and protective functions.

The advent of digital computing and its success made analog computers largely obsolete in 1950s and 1960s, though they remain in use in some specific applications, like the flight computer in aircraft, and for teaching control systems in universities.

2.1 Setup

Setting up an analog computer required scale factors to be chosen, along with initial conditions—that is, starting values. Another essential was creating the required network of interconnections between computing elements. Sometimes it was necessary to re-think the structure of the problem so that the computer would function satisfactorily. No variables could be allowed to exceed the computer's limits, and differentiation was to be avoided, typically by rearranging the "network" of interconnects, using integrators in a different sense.

Running an electronic analog computer, assuming a satisfactory setup, started with the computer held with some variables fixed at their initial values. Moving a switch released the holds and permitted the problem to run. In some instances, the computer could, after a certain running time interval, repeatedly return to the initial-conditions state to reset the problem, and run it again.

2.2 Timeline of analog computers

See also: History of computing hardware

2.2.1 Precursors

See also: Timeline of computing hardware 2400 BC–1949

This is a list of examples of early computation devices which are considered to be precursors of the modern computers. Some of them may even have been dubbed as 'computers' by the press, although they may fail to fit the modern definitions.

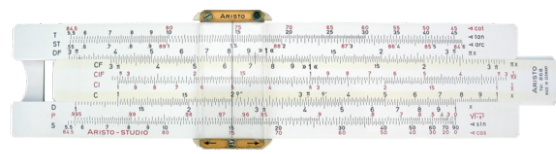
The ancient Greek-designed Antikythera mechanism, dating between 150 to 100 BC, is the world's oldest known analog computer.

The Antikythera mechanism is believed to be the earliest known mechanical analog "computer", according to Derek J. de Solla Price.[2] It was designed to calculate astronomical positions. It was discovered in 1901 in the Antikythera wreck off the Greek island of Antikythera, between Kythera and Crete, and has been dated to *circa* 100 BC. Devices of a level of complexity comparable to that of the Antikythera mechanism would not reappear until a thousand years later.

Many mechanical aids to calculation and measurement were constructed for astronomical and navigation use. The planisphere was a star chart invented by Abū Rayḥān al-Bīrūnī in the early 11th century.[3] The astrolabe was invented in the Hellenistic world in either the 1st or 2nd centuries BC and is often attributed to Hipparchus. A combination of the planisphere and dioptra, the astrolabe was effectively an analog computer capable of working out several different kinds of problems in spherical astronomy. An astrolabe incorporating a mechanical calendar computer[4][5] and gear-wheels was invented by Abi Bakr of Isfahan, Persia in 1235.[6] Abū Rayhān al-Bīrūnī invented the first mechanical geared lunisolar calendar astrolabe,[7] an early fixed-wired knowledge processing machine[8] with a gear train and gear-wheels,[9] *circa* 1000 AD.

The sector, a calculating instrument used for solving problems in proportion, trigonometry, multiplication and division, and for various functions, such as squares and cube roots, was developed in the late 16th century and found application in gunnery, surveying and navigation.

The planimeter was a manual instrument to calculate the area of a closed figure by tracing over it with a mechanical linkage.



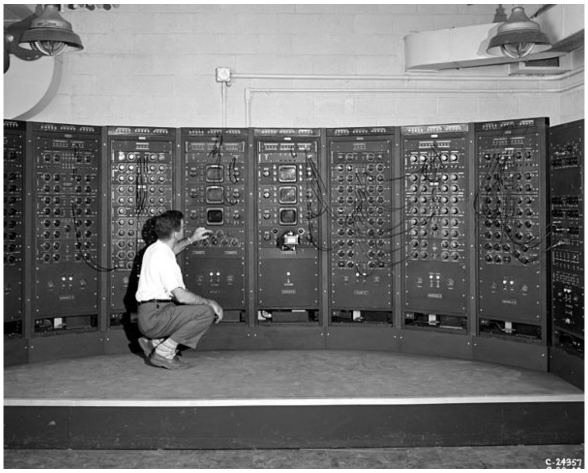
A slide rule

The slide rule was invented around 1620–1630, shortly after the publication of the concept of the logarithm. It is a hand-operated analog computer for doing multiplication and division. As slide rule development progressed, added scales provided reciprocals, squares and square roots, cubes and cube roots, as well as transcendental functions such as logarithms and exponentials, circular and hyperbolic trigonometry and other functions. Aviation is one of the few fields where slide rules are still in widespread use, particularly for solving time–distance problems in light aircraft.

The tide-predicting machine invented by Sir William Thomson in 1872 was of great utility to navigation in shallow waters. It used a system of pulleys and wires to automatically calculate predicted tide levels for a set period at a particular location.

The differential analyser, a mechanical analog computer designed to solve differential equations by integration, used wheel-and-disc mechanisms to perform the integration. In 1876 Lord Kelvin had already discussed the possible construction of such calculators, but he had been stymied by the limited output torque of the ball-and-disk integrators.[10] In a differential analyzer, the output of one integrator drove the input of the next integrator, or a graphing output. The torque amplifier was the advance that allowed these machines to work. Starting in the 1920s, Vannevar Bush and others developed mechanical differential analyzers.

2.2.2 Modern era



Analog computing machine at the Lewis Flight Propulsion Laboratory circa 1949.

Heathkit EC-1 educational analog computer

The Dumaresq was a mechanical calculating device invented around 1902 by Lieutenant John Dumaresq of the Royal Navy. It was an analog computer which related vital variables of the fire control problem to the movement of one's own ship and that of a target ship. It was often used with other devices, such as a Vickers range clock to generate range and deflection data so the gun sights of the ship could be continuously set. A number of versions of the Dumaresq were produced of increasing complexity as development proceeded.

By 1912 Arthur Pollen had developed an electrically driven mechanical analog computer for fire-control systems, based on the differential analyser. It was used by the Imperial Russian Navy in World War I.

Starting in 1929, AC network analyzers were constructed to solve calculation problems related to electrical power systems that were too large to solve with numerical methods at the time.[11] These were essentially scale models of the electrical properties of the full-size system. Since network analyzers could handle problems too large for analytic methods or hand computation, they were also used to solve problems in nuclear physics and in the design of structures. More than 50 large network analyzers were built by the end of the 1950s.

World War II era gun directors, gun data computers, and bomb sights used mechanical analog computers. Mechanical analog computers were very important in gun fire control in World War II, The Korean War and well past the Vietnam War; they were made in significant numbers.

The FERMIAC was an analog computer invented by physicist Enrico Fermi in 1947 to aid in his studies of neutron transport.[12] Project Cyclone was an analog computer developed by Reeves in 1950 for the analysis and design of dynamic systems.[13] Project Typhoon was an analog computer developed by RCA in 1952. It consisted of over 4000 electron tubes and used 100 dials and 6000 plug-in connectors to program.[14] The MONIAC Computer was a hydraulic model of a national economy first unveiled in 1949.

Computer Engineering Associates was spun out of Caltech in 1950 to provide commercial services using the "Direct Analogy Electric Analog Computer" ("the largest and most impressive general-purpose analyzer facility for the solution of field problems") developed there by Gilbert D. McCann, Charles H. Wilts, and Bart Locanthi.[15][16]

Educational analog computers illustrated the principles of analog calculation. The Heathkit EC-1, a $199 educational analog computer, was made by the Heath Company, USA c. 1960.[17] It was programmed using patch cords that connected nine operational amplifiers and other components.[18] General Electric also marketed an "educational" analog computer kit of a simple design in the early 1960s consisting of a two transistor tone generator and three potentiometers wired such that the frequency of the oscillator was nulled when the potentiometer dials were positioned by hand to satisfy an equation. The relative resistance of the potentiometer was then equivalent to the formula of the equation being solved. Multiplication or division could be performed depending on which dials were considered inputs and which was the output. Accuracy and resolution was limited and a simple slide rule was more accurate; however, the unit did demonstrate the basic principle.

In industrial process control, thousands of analog loop controllers were used to automatically regulate temperature, flow, pressure, or other process conditions. The technology of these controllers ranged from purely mechanical integrators, through vacuum-tube and solid-state devices, to emulation of analog controllers by microprocessors.

2.3 Electronic analog computers

Polish analog computer AKAT-1

The similarity between linear mechanical components, such as springs and dashpots (viscous-fluid dampers), and electrical components, such as capacitors, inductors, and resistors is striking in terms of mathematics. They can be modeled using equations of the same form.

However, the difference between these systems is what makes analog computing useful. If one considers a simple mass–spring system, constructing the physical system would require making or modifying the springs and masses. This would be followed by attaching them to each other and an appropriate anchor, collecting test equipment with the appropriate input range, and finally, taking measurements. In more complicated cases, such as suspensions for racing cars, experimental construction, modification, and testing is both complicated and expensive.

The electrical equivalent can be constructed with a few operational amplifiers (op amps) and some passive linear components; all measurements can be taken directly with an oscilloscope. In the circuit, the (simulated) 'stiffness of the spring', for instance, can be changed by adjusting the parameters of a capacitor. The electrical system is an analogy to the physical system, hence the name, but it is less expensive to construct, generally safer, and typically much easier to modify.

As well, an electronic circuit can typically operate at higher frequencies than the system being simulated. This allows the simulation to run faster than real time (which could, in some instances, be hours, weeks, or longer). Experienced users of electronic analog computers said that they offered a comparatively intimate control and understanding of the problem, relative to digital simulations.

The drawback of the mechanical-electrical analogy is that electronics are limited by the range over which the variables may vary. This is called dynamic range. They are also limited by noise levels. Floating-point digital calculations have a comparatively huge dynamic range.

These electric circuits can also easily perform a wide variety of simulations. For example, voltage can simulate water pressure and electric current can simulate rate of flow in terms of cubic metres per second. An integrator can provide the total accumulated volume of liquid, using an input current proportional to the (possibly varying) flow rate.

Analog computers are especially well-suited to representing situations described by differential equations. Occasionally, they were used when a differential equation proved very difficult to solve by traditional means.

The accuracy of an analog computer is limited by its computing elements as well as quality of the internal power and electrical interconnections. The precision of the analog computer readout was limited chiefly by the precision of the readout equipment used, generally three or four significant figures. The precision of a digital computer is limited by the word size; arbitrary-precision arithmetic, while relatively slow, provides any practical degree of precision that might be needed.

Many small computers dedicated to specific computations are still part of industrial regulation equipment, but from the 1950s to the 1970s, general-purpose analog computers were the only systems fast enough for real time simulation of dynamic systems, especially in the aircraft, military and aerospace field.

In the 1960s, the major manufacturer was Electronic Associates of Princeton, New Jersey, with its 231R Analog Computer (vacuum tubes, 20 integrators) and subsequently its 8800 Analog Computer (solid state operational amplifiers, 64 integrators). Its challenger was Applied Dynamics of Ann Arbor, Michigan.

Although the basic technology for analog computers is usually operational amplifiers (also called "continuous current amplifiers" because they have no low frequency limitation), in the 1960s an attempt was made in the French ANALAC computer to use an alternative technology: medium frequency carrier and non dissipative reversible circuits.

In the 1970s every big company and administration concerned with problems in dynamics had a big analog computing center, for example:

- *In the USA*: NASA (Huntsville, Houston), Martin Marietta (Orlando), Lockheed, Westinghouse, Hughes Aircraft
- *In Europe*: CEA (French Atomic Energy Commission), MATRA, Aerospatiale, BAC (British Aircraft Corporation).

2.4 Analog–digital hybrids

Analog computing devices are fast, digital computing devices are more versatile and accurate, so the idea is to combine the two processes for the best efficiency. An example of such hybrid elementary device is the hybrid multiplier where one input is an analog signal, the other input is a digital signal and the output is analog. It acts as an analog potentiometer upgradable digitally. This kind of hybrid technique is mainly used for fast dedicated real time computation when computing time is very critical as signal processing for radars and generally for controllers in embedded systems.

In the early 1970s analog computer manufacturers tried to tie together their analog computer with a digital computer to get the advantages of the two techniques. In such systems, the digital computer controlled the analog computer, providing initial set-up, initiating multiple analog runs, and automatically feeding and collecting data. The digital computer may also participate to the calculation itself using analog-to-digital and digital-to-analog converters.

The largest manufacturer of hybrid computers was Electronics Associates. Their hybrid computer model 8900 was made of a digital computer and one or more analog consoles. These systems were mainly dedicated to large projects such as the Apollo program and Space Shuttle at NASA, or Ariane in Europe, especially during the integration step where at the beginning everything is simulated, and progressively real components replace their simulated part.

Only one company was known as offering general commercial computing services on its hybrid computers, CISI of France, in the 1970s.

The best reference in this field is the 100 000 simulations runs for each certification of the automatic landing systems of Airbus and Concorde aircraft.

After 1980, purely digital computers progressed more and more rapidly and were fast enough to compete with analog computers. One key to the speed of analog computers was their fully parallel computation, but this was also a limitation. The more equations required for a problem, the more analog components were needed, even when the problem wasn't time critical. “Programming” a problem meant interconnecting the analog operators; even with a removable wiring panel this was not very versatile. Today there are no more big hybrid computers, but only hybrid components.

2.5 Implementations

2.5.1 Mechanical analog computers

While a wide variety of mechanisms have been developed throughout history, some stand out because of their theoretical importance, or because they were manufactured in significant quantities.

Most practical mechanical analog computers of any significant complexity used rotating shafts to carry variables from one mechanism to another. Cables and pulleys were used in a Fourier synthesizer, a tide-predicting machine, which summed the individual harmonic components. Another category, not nearly as well known, used rotating shafts only for input and output, with precision racks and pinions. The racks were connected to linkages that performed the computation. At least one US Naval sonar fire control computer of the later 1950s, made by Librascope, was of this type, as was the principal computer in the Mk. 56 Gun Fire Control System.

Online, there is a remarkably clear illustrated reference (OP 1140) that describes[19] the fire control computer mechanisms. For adding and subtracting, precision miter-gear differentials were in common use in some computers; the Ford Instrument Mark I Fire Control Computer contained about 160 of them.

Integration with respect to another variable was done by a rotating disc driven by one variable. Output came from a pickoff device (such as a wheel) positioned at a radius on the disc proportional to the second variable. (A carrier with a pair of steel balls supported by small rollers worked especially well. A roller, its axis parallel to the disc's surface, provided the output. It was held against the pair of balls by a spring.)

Arbitrary functions of one variable were provided by cams, with gearing to convert follower movement to shaft rotation.

Functions of two variables were provided by three-dimensional cams. In one good design, one of the variables rotated the cam. A hemispherical follower moved its carrier on a pivot axis parallel to that of the cam's rotating axis. Pivoting motion was the output. The second variable moved the follower along the axis of the cam. One practical application was ballistics in gunnery.

Coordinate conversion from polar to rectangular was done by a mechanical resolver (called a "component solver" in US Navy fire control computers). Two discs on a common axis positioned a sliding block with pin (stubby shaft) on it. One disc was a face cam, and a follower on the block in the face cam's groove set the radius. The other disc, closer to the pin, contained a straight slot in which the block moved. The input angle rotated the latter disc (the face cam disc, for an unchanging radius, rotated with the other (angle) disc; a differential and a few gears did this correction).

Referring to the mechanism's frame, the location of the pin corresponded to the tip of the vector represented by the angle and magnitude inputs. Mounted on that pin was a square block.

Rectilinear-coordinate outputs (both sine and cosine, typically) came from two slotted plates, each slot fitting on the block just mentioned. The plates moved in straight lines, the movement of one plate at right angles to that of the other. The slots were at right angles to the direction of movement. Each plate, by itself, was like a Scotch yoke, known to steam engine enthusiasts.

During World War II, a similar mechanism converted rectilinear to polar coordinates, but it was not particularly successful and was eliminated in a significant redesign (USN, Mk. 1 to Mk. 1A).

Multiplication was done by mechanisms based on the geometry of similar right triangles. Using the trigonometric terms for a right triangle, specifically opposite, adjacent, and hypotenuse, the adjacent side was fixed by construction. One variable changed the magnitude of the opposite side. In many cases, this variable changed sign; the hypotenuse could coincide with the adjacent side (a zero input), or move beyond the adjacent side, representing a sign change.

Typically, a pinion-operated rack moving parallel to the (trig.-defined) opposite side would position a slide with a slot coincident with the hypotenuse. A pivot on the rack let the slide's angle change freely. At the other end of the slide (the angle, in trig, terms), a block on a pin fixed to the frame defined the vertex between the hypotenuse and the adjacent side.

At any distance along the adjacent side, a line perpendicular to it intersects the hypotenuse at a particular point. The distance between that point and the adjacent side is some fraction that is the product of *1* the distance from the vertex, and *2* the magnitude of the opposite side.

The second input variable in this type of multiplier positions a slotted plate perpendicular to the adjacent side. That slot contains a block, and that block's position in its slot is determined by another block right next to it. The latter slides along the hypotenuse, so the two blocks are positioned at a distance from the (trig.) adjacent side by an amount proportional to the product.

To provide the product as an output, a third element, another slotted plate, also moves parallel to the (trig.) opposite side of the theoretical triangle. As usual, the slot is perpendicular to the direction of movement. A block in its slot, pivoted to the hypotenuse block positions it.

A special type of integrator, used at a point where only moderate accuracy was needed, was based on a steel ball, instead of a disc. It had two inputs, one to rotate the ball, and the other to define the angle of the ball's rotating axis. That axis was always in a plane that contained the axes of two movement-pickoff rollers, quite similar to the mechanism of a rolling-ball computer mouse (in this mechanism, the pickoff rollers were roughly the same diameter as the ball). The pickoff roller axes were at right angles.

A pair of rollers "above" and "below" the pickoff plane were mounted in rotating holders that were geared together. That gearing was driven by the angle input, and established the rotating axis of the ball. The other input rotated the "bottom" roller to make the ball rotate.

Essentially, the whole mechanism, called a component integrator, was a variable-speed drive with one motion input and two outputs, as well as an angle input. The angle input varied the ratio (and direction) of coupling between the "motion" input and the outputs according to the sine and cosine of the input angle.

Although they did not accomplish any computation, electromechanical position servos were essential in mechanical analog computers of the "rotating-shaft" type for providing operating torque to the inputs of subsequent computing mechanisms, as well as driving output data-transmission devices such as large torque-transmitter synchros in naval computers.

Other non-computational mechanisms included internal odometer-style counters with interpolating drum dials for indicating internal variables, and mechanical multi-turn limit stops.

Considering that accurately controlled rotational speed in analog fire-control computers was a basic element of their accuracy, there was a motor with its average speed controlled by a balance wheel, hairspring, jeweled-bearing differential, a twin-lobe cam, and spring-loaded contacts (ship's AC power frequency was not necessarily accurate, nor dependable enough, when these computers were designed).

2.5.2 Electronic analog computers

Electronic analog computers typically have front panels with numerous jacks (single-contact sockets) that permit patch cords (flexible wires with plugs at both ends) to create the interconnections which define the problem setup. In addition, there are precision high-resolution potentiometers (variable resistors) for setting up (and, when needed, varying) scale factors. In addition, there is likely to be a zero-center analog pointer-type meter for modest-accuracy voltage measurement. Stable, accurate voltage sources provide known magnitudes.

Typical electronic analog computers contain anywhere from a few to a hundred or more operational amplifiers ("op amps"), named because they perform mathematical operations. Op amps are a particular type of feedback amplifier with very high gain and stable input (low and stable offset). They are always used with precision feedback components that, in operation, all but cancel out the currents arriving from input components. The majority of op amps in a representative setup are summing amplifiers, which add and subtract analog voltages, providing the result at their output jacks. As well, op amps with capacitor feedback are usually included in a setup; they integrate the sum of their inputs with respect to time.

Integrating with respect to another variable is the nearly exclusive province of mechanical analog integrators; it is almost never done in electronic analog computers. However, given that a problem solution does not change with time, time can serve as one of the variables.

Other computing elements include analog multipliers, nonlinear function generators, and analog comparators.

Electrical elements such as inductors and capacitors used in electrical analog computers had to be carefully manufactured to reduce non-ideal effects. For example, in the construction of AC power network analyzers, one motive for using higher frequencies for the calculator (instead of the actual power frequency) was that higher-quality inductors could be more easily made. Many general-purpose analog computers avoided the use of inductors entirely, re-casting the problem in a form that could be solved using only resistive and capacitive elements, since high-quality capacitors are relatively easy to make.

The use of electrical properties in analog computers means that calculations are normally performed in real time (or faster), at a speed determined mostly by the frequency response of the operational amplifiers and other computing elements. In the history of electronic analog computers, there were some special high-speed types.

Nonlinear functions and calculations can be constructed to a limited precision (three or four digits) by designing function generators — special circuits of various combinations of resistors and diodes to provide the nonlinearity. Typically, as the input voltage increases, progressively more diodes conduct.

When compensated for temperature, the forward voltage drop of a transistor's base-emitter junction can provide a usably accurate logarithmic or exponential function. Op amps scale the output voltage so that it is usable with the rest of the computer.

Any physical process which models some computation can be interpreted as an analog computer. Some examples, invented for the purpose of illustrating the concept of analog computation, include using a bundle of spaghetti as a model of sorting numbers; a board, a set of nails, and a rubber band as a model of finding the convex hull of a set of points; and strings tied together as a model of finding the shortest path in a network. These are all described in Dewdney (1984).

2.6 Components

A 1960 Newmark analogue computer, made up of five units. This computer was used to solve differential equations and is currently housed at the Cambridge Museum of Technology.

Analog computers often have a complicated framework, but they have, at their core, a set of key components which perform the calculations, which the operator manipulates through the computer's framework.

Key hydraulic components might include pipes, valves and containers.

Key mechanical components might include rotating shafts for carrying data within the computer, miter gear differentials, disc/ball/roller integrators, cams (2-D and 3-D), mechanical resolvers and multipliers, and torque servos.

Key electrical/electronic components might include:

- Precision resistors and capacitors
- operational amplifiers
- Multipliers
- potentiometers
- fixed-function generators

The core mathematical operations used in an electric analog computer are:

- addition
- integration with respect to time
- inversion
- multiplication
- exponentiation
- logarithm
- division

In some analog computer designs, multiplication is much preferred to division. Division is carried out with a multiplier in the feedback path of an Operational Amplifier.

Differentiation with respect to time is not frequently used, and in practice is avoided by redefining the problem when possible. It corresponds in the frequency domain to a high-pass filter, which means that high-frequency noise is amplified; differentiation also risks instability.

2.7 Limitations

In general, analog computers are limited by non-ideal effects. An analog signal is composed of four basic components: DC and AC magnitudes, frequency, and phase. The real limits of range on these characteristics limit analog computers. Some of these limits include the operational amplifier offset, finite gain, and frequency response, noise floor, non-linearities, temperature coefficient, and parasitic effects within semiconductor devices. For commercially available electronic components, ranges of these aspects of input and output signals are always figures of merit.

2.8 Decline

In 1950s to 1970s, digital computers based on first vacuum tubes, transistors, integrated circuits and then micro-processors became more economical and precise. This led digital computers to largely replace analog computers. Even so, some research in analog computation is still being done. A few universities still use analog computers to teach control system theory. The American company Comdyna manufactures small analog computers.[20] At Indiana University Bloomington, Jonathan Mills has developed the Extended Analog Computer based on sampling voltages in a foam sheet. At the Harvard Robotics Laboratory, analog computation is a research topic. [Lyric Semiconductor]'s error correction circuits use analog probabilistic signals. Slide rules are still popular among aircraft personnel.

2.9 Resurgence in VLSI technology

With the development of very-large-scale integration (VLSI) technology, Yannis Tsividis' group at Columbia University has been revisiting analog/hybrid computers design in standard CMOS process. Two VLSI chips have been developed, an 80th-order analog computer (250 nm) by Glenn Cowan[21] in 2005[22] and an 4th-order hybrid computer (65 nm) developed by Ning Guo[23] in 2015,[24] both targeting at energy-efficient ODE/PDEs applications. Glenn's chip contains 16 macros, in which there are 25 analog computing blocks, namely integrators, multipliers, fanouts, few nonlinear blocks. Ning's chip contains one macro block, in which there are 26 computing blocks including integrators, multipliers, fanouts, ADCs, SRAMs and DACs. Arbitrary nonlinear function generation is made possible by the ADC+SRAM+DAC chain, where the SRAM block stores the nonlinear function data. The experiments from the related publications revealed that VLSI analog/hybrid computers demonstrated about 1~2 orders magnitude of advantage in both solution time and energy while achieving accuracy within 5%, which points to the promise of using analog/hybrid computing techniques in the area of energy-efficient approximate computing.

2.10 Practical examples

These are examples of analog computers that have been constructed or practically used:

- Boeing B-29 Superfortress Central Fire Control System
- Deltar
- Kerrison Predictor
- Leonardo Torres y Quevedo's Analogue Calculating Machines based on “fusee sans fin”
- Librascope, aircraft weight and balance computer
- Mechanical computer
- Mechanical integrators, for example, the planimeter
- Nomogram
- Norden bombsight
- Rangekeeper and related fire control computers
- Scanimate
- Torpedo Data Computer
- Torquetum
- Water integrator

Analog (audio) synthesizers can also be viewed as a form of analog computer, and their technology was originally based in part on electronic analog computer technology. The ARP 2600's Ring Modulator was actually a moderate-accuracy analog multiplier.

The Simulation Council (or Simulations Council) was an association of analog computer users in USA. It is now known as The Society for Modeling and Simulation International. The Simulation Council newsletters from 1952 to 1963 are available online and show the concerns and technologies at the time, and the common use of analog computers for missilry.[25]

2.11 Real computers

Computer theorists often refer to idealized analog computers as real computers (because they operate on the set of real numbers). Digital computers, by contrast, must first quantize the signal into a finite number of values, and so can only work with the rational number set (or, with an approximation of irrational numbers).

These idealized analog computers may *in theory* solve problems that are intractable on digital computers; however as mentioned, in reality, analog computers are far from attaining this ideal, largely because of noise minimization problems. *In theory*, ambient noise is limited by quantum noise (caused by the quantum movements of ions). Ambient noise may be severely reduced – but never to zero – by using cryogenically cooled parametric amplifiers. Moreover, given unlimited time and memory, the (ideal) digital computer may also solve real number problems.

2.12 See also

- Signal (electrical engineering)
- Signal (computing)
- Differential equation
- Dynamical system
- Chaos theory
- General purpose analog computer
- Analogical models
- Field-programmable analog array
- Voskhod Spacecraft “Globus” IMP navigation instrument

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Chapter 3

Personal computer

A **personal computer** (**PC**) is a general-purpose computer whose size, capabilities, and original sale price make it useful for individuals, and is intended to be operated directly by an end-user with no intervening computer time-sharing models that allowed larger, more expensive minicomputer and mainframe systems to be used by many people, usually at the same time.

Software applications for most personal computers include, but are not limited to, word processing, spreadsheets, databases, web browsers and e-mail clients, digital media playback, games and many personal productivity and special-purpose software applications. Modern personal computers often have connections to the Internet, allowing access to the World Wide Web and a wide range of other resources. Personal computers may be connected to a local area network (LAN), either by a cable or a wireless connection. A personal computer may be a laptop computer or a desktop computer running an operating system such as Windows, Linux (and the various operating systems based on it), or Macintosh OS.

Early computer owners usually had to write their own programs to do anything useful with the machines, which even did not include an operating system. The very earliest microcomputers, equipped with a front panel, required hand-loading of a bootstrap program to load programs from external storage (paper tape, cassettes, or eventually diskettes). Before very long, automatic booting from permanent read-only memory became universal. Today's users have access to a wide range of commercial software, freeware and free and open-source software, which are provided in ready-to-run or ready-to-compile form. Software for personal computers, such as applications and video games, are typically developed and distributed independently from the hardware or OS manufacturers, whereas software for many mobile phones and other portable systems is approved and distributed through a centralized online store.[1][2]

Since the early 1990s, Microsoft operating systems and Intel hardware dominated much of the personal computer market, first with MS-DOS and then with Windows. Popular alternatives to Microsoft's Windows operating systems include Apple's OS X and free open-source Unix-like operating systems such as Linux and BSD. AMD provides the major alternative to Intel's processors. ARM architecture processors now outnumber Intel's (and compatibles) in smartphones and tablets, that are also personal computers, outnumbering the traditional kind.

3.1 History

Main article: History of personal computers

The Programma 101 was the first commercial "desktop personal computer", produced by the Italian company Olivetti and invented by the Italian engineer Pier Giorgio Perotto, inventor of the magnetic card system. The project started in 1962. It was launched at the 1964 New York World's Fair, and volume production began in 1965, the computer retailing for $3,200.[3]

NASA bought at least ten Programma 101s and used them for the calculations for the 1969 Apollo 11 Moon landing. The ABC Network used the Programma 101 to predict the presidential election of 1968, and the U.S. military used the machine to plan their operations in the Vietnam War. The Programma 101 was not used in schools, hospitals, government offices. This marked the beginning of the era of the personal computer.

In 1968, Hewlett-Packard was ordered to pay about $900,000 in royalties to Olivetti after their Hewlett-Packard 9100A was ruled to have copied some of the solutions adopted in the Programma 101, including the magnetic card, the architecture and other similar components.[3]

The Soviet MIR series of computers was developed from 1965 to 1969 in a group headed by Victor Glushkov. It was designed as a relatively small-scale computer for use in engineering and scientific applications and contained a hardware implementation of a high-level programming language. Another innovative feature for that time was the user interface combining a keyboard with a monitor and light pen for correcting texts and drawing on screen.[4]

In what was later to be called the Mother of All Demos, SRI researcher Douglas Engelbart in 1968 gave a preview of what would become the staples of daily working life in the 21st century: e-mail, hypertext, word processing, video conferencing and the mouse. The demonstration required technical support staff and a mainframe time-sharing computer that were far too costly for individual business use at the time.

Commodore PET in 1983 (at American Museum of Science and Energy)

By the early 1970s, people in academic or research institutions had the opportunity for single-person use of a computer system in interactive mode for extended durations, although these systems would still have been too expensive to be owned by a single person.

Early personal computers—generally called microcomputers—were often sold in a kit form and in limited volumes, and were of interest mostly to hobbyists and technicians. Minimal programming was done with toggle switches to enter instructions, and output was provided by front panel lamps. Practical use required adding peripherals such as keyboards, computer displays, disk drives, and printers. Micral N was the earliest commercial, non-kit microcomputer based on a microprocessor, the Intel 8008. It was built starting in 1972 and about 90,000 units were sold.

In 1973 the IBM Los Gatos Scientific Center developed a portable computer prototype called SCAMP (Special Computer APL Machine Portable) based on the IBM PALM processor with a Philips compact cassette drive, small CRT and full function keyboard. SCAMP emulated an IBM 1130 minicomputer in order to run APL\1130.[5] In 1973 APL was generally available only on mainframe computers, and most desktop sized microcomputers such as the Wang 2200 or HP 9800 offered only BASIC. Because SCAMP was the first to emulate APL\1130 performance on a portable, single user computer, *PC Magazine* in 1983 designated SCAMP a "revolutionary concept" and "the world's first personal computer".[5][6] This seminal, single user portable computer now resides in the Smithsonian Institution, Washington, D.C.. Successful demonstrations of the 1973 SCAMP prototype led to the IBM 5100 portable microcomputer launched in 1975 with the ability to be programmed in both APL and BASIC for engineers, analysts, statisticians and other business problem-solvers. In the late 1960s such a machine would have been nearly as large as two desks and would have weighed about half a ton.[5]

Another seminal product in 1973 was the Xerox Alto, developed at Xerox's Palo Alto Research Center (PARC), it had a graphical user interface (GUI) which later served as inspiration for Apple Computer's Macintosh, and Microsoft's Windows operating system. Also in 1973 Hewlett Packard introduced fully BASIC programmable microcomputers that fit entirely on top of a desk, including a keyboard, a small one-line display and printer. The Wang 2200 microcomputer of 1973 had a full-size cathode ray tube (CRT) and cassette tape storage.[7] These were generally expensive specialized computers sold for business or scientific uses. The introduction of the microprocessor, a single chip with all the circuitry that formerly occupied large cabinets, led to the proliferation of personal computers after 1975.

IBM Personal Computer XT in 1988

In 1976 Steve Jobs and Steve Wozniak sold the Apple I computer circuit board, which was fully prepared and contained about 30 chips. The Apple I computer differed from the other hobby computers of the time at the beckoning of Paul Terrell owner of the Byte Shop who gave Steve Jobs his first purchase order for 50 Apple I computers only if the computers were assembled and tested and not a kit computer so he would have computers to sell to everyone, not just people that could assemble a computer kit. The Apple

I as delivered was still a kit computer as it did not have a power supply, case, or keyboard as delivered to the Byte Shop.

The first successfully mass marketed personal computer was the Commodore PET introduced in January 1977, but back-ordered and not available until later in the year.[8] At the same time, the Apple II (usually referred to as the "Apple") was introduced[9] (June 1977), and the TRS-80 from Tandy Corporation / Tandy Radio Shack in summer 1977, delivered in September in a small number. Mass-market ready-assembled computers allowed a wider range of people to use computers, focusing more on software applications and less on development of the processor hardware.

The 8-bit PMD 85 personal computer produced in 1985–1990 by the Tesla company in the former socialist Czechoslovakia. This computer was produced locally (in Piešťany) due to a lack of foreign currency with which to buy systems from the West.

IBM 5150, released in 1981

During the early 1980s, home computers were further developed for household use, with software for personal productivity, programming and games. They typically could be used with a television already in the home as the computer display, with low-detail blocky graphics and a limited color range, and text about 40 characters wide by 25 characters tall. Sinclair Research,[10] a UK company, produced the ZX Series – the ZX80 (1980), ZX81 (1981), and the ZX Spectrum; the latter was introduced in 1982, and totaled 8 million unit sold. Following came the Commodore 64, totaled 17 million units sold.[11][12]

In the same year, the NEC PC-98 was introduced, which was a very popular personal computer that sold in more than 18 million units.[13] Another famous personal computer, the revolutionary Amiga 1000, was unveiled by Commodore on July 23, 1985. The Amiga 1000 featured a multitasking, windowing operating system, color graphics with a 4096-color palette, stereo sound, Motorola 68000 CPU, 256 kB RAM, and 880 kB 3.5-inch disk drive, for US$1,295.[14]

Somewhat larger and more expensive systems (for example, running CP/M), or sometimes a home computer with additional interfaces and devices, although still low-cost compared with minicomputers and mainframes, were aimed at office and small business use, typically using "high resolution" monitors capable of at least 80 column text display, and often no graphical or color drawing capability.

Workstations were characterized by high-performance processors and graphics displays, with large-capacity local disk storage, networking capability, and running under a multitasking operating system.

Eventually, due to the influence of the IBM PC on the personal computer market, personal computers and home computers lost any technical distinction. Business computers acquired color graphics capability and sound, and home computers and game systems users used the same processors and operating systems as office workers. Mass-market computers had graphics capabilities and memory comparable to dedicated workstations of a few years before. Even local area networking, originally a way to allow business computers to share expensive mass storage and peripherals, became a standard feature of personal computers used at home.

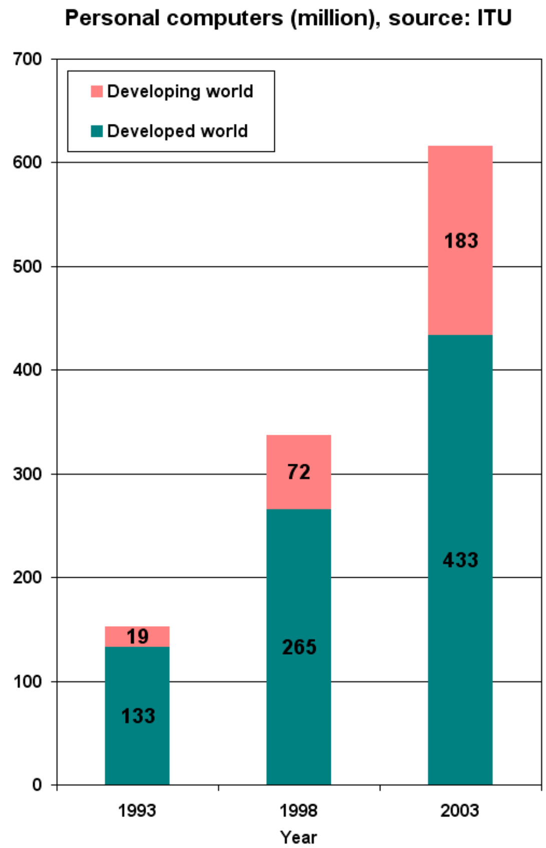
In 1982 "The Computer" was named Machine of the Year by *Time* Magazine.

In the 2010s, several companies such as Hewlett-Packard and Sony sold off their PC and laptop divisions. As a result, the personal computer was declared dead several times during this time.[15]

3.1.1 Market and sales

See also: Market share of personal computer vendors

In 2001, 125 million personal computers were shipped in comparison to 48,000 in 1977.[16] More than 500 million personal computers were in use in 2002 and one billion per-



Personal computers worldwide in million distinguished by developed and developing world

sonal computers had been sold worldwide from the mid-1970s up to this time. Of the latter figure, 75% were professional or work related, while the rest were sold for personal or home use. About 81.5% of personal computers shipped had been desktop computers, 16.4% laptops and 2.1% servers. The United States had received 38.8% (394 million) of the computers shipped, Europe 25% and 11.7% had gone to the Asia-Pacific region, the fastest-growing market as of 2002. The second billion was expected to be sold by 2008.[17] Almost half of all households in Western Europe had a personal computer and a computer could be found in 40% of homes in United Kingdom, compared with only 13% in 1985.[18]

The global personal computer shipments were 350.9 million units in 2010,[19] 308.3 million units in 2009[20] and 302.2 million units in 2008.[21][22] The shipments were 264 million units in the year 2007, according to iSuppli,[23] up 11.2% from 239 million in 2006.[24] In 2004, the global shipments were 183 million units, an 11.6% increase over 2003.[25] In 2003, 152.6 million computers were shipped, at an estimated value of $175 billion.[26] In 2002, 136.7 million PCs were shipped, at an estimated value of $175 billion.[26] In 2000, 140.2 million personal computers were shipped, at an estimated value of $226 billion.[26] Worldwide shipments of personal computers surpassed the 100-million mark in 1999, growing to 113.5 million units from 93.3 million units in 1998.[27] In 1999, Asia had 14.1 million units shipped.[28]

As of June 2008, the number of personal computers in use worldwide hit one billion,[29] while another billion is expected to be reached by 2014. Mature markets like the United States, Western Europe and Japan accounted for 58% of the worldwide installed PCs. The emerging markets were expected to double their installed PCs by 2012 and to take 70% of the second billion PCs. About 180 million computers (16% of the existing installed base) were expected to be replaced and 35 million to be dumped into landfill in 2008. The whole installed base grew 12% annually.[30][31]

Based on International Data Corporation (IDC) data for Q2 2011, for the first time China surpassed US in PC shipments by 18.5 million and 17.7 million respectively. This trend reflects the rising of emerging markets as well as the relative stagnation of mature regions.[32]

In the developed world, there has been a vendor tradition to keep adding functions to maintain high prices of personal computers. However, since the introduction of the One Laptop per Child foundation and its low-cost XO-1 laptop, the computing industry started to pursue the price too. Although introduced only one year earlier, there were 14 million netbooks sold in 2008.[33] Besides the regular computer manufacturers, companies making especially rugged versions of computers have sprung up, offering alternatives for people operating their machines in extreme weather or environments.[34]

In 2011, Deloitte consulting firm predicted that, smartphones and tablet computers as computing devices would surpass the PCs sales[37] (as has happened since 2012). As of 2013, worldwide sales of PCs had begun to fall as many consumers moved to tablets and smartphones for gifts and personal use. Sales of 90.3 million units in the 4th quarter of 2012 represented a 4.9% decline from sales in the 4th quarter of 2011.[38] Global PC sales fell sharply in the first quarter of 2013, according to IDC data. The 14% year-over-year decline was the largest on record since the firm began tracking in 1994, and double what analysts had been expecting.[39][40] The decline of Q2 2013 PC shipments marked the fifth straight quarter of falling sales.[41] "This is horrific news for PCs," remarked an analyst. "It's all about mobile computing now. We have definitely reached the tipping point."[39] Data from Gartner Inc. showed a similar decline for the same time period.[39] China's Lenovo Group bucked the general trend as strong sales to first time buyers in the developing world allowed the company's sales to stay flat overall.[39] Windows 8, which was designed to look similar to tablet/smartphone software, was cited as a contributing factor in the decline of new PC sales. "Unfortunately, it seems clear that the Windows 8 launch not only didn't provide a positive boost to the PC market, but appears to have slowed the market," said IDC Vice President Bob O'Donnell.[40]

In August 2013, Credit Suisse published research findings that attributed around 75% of the operating profit share of the PC industry to Microsoft (operating system) and Intel (semiconductors).[42]

According to IDC, in 2013 PC shipments dropped by 9.8% as the greatest drop-ever in line with consumers trends to use mobile devices.[43]

3.1.2 Average selling price

Selling prices of personal computers steadily declined due to lower costs of production and manufacture, while the capabilities of computers increased. In 1975, an Altair kit sold for only around US $400, but required customers to solder components into circuit boards; peripherals required to interact with the system in alphanumeric form instead of blinking lights would add another $2,000, and the resultant system was only of use to hobbyists.[44]

At their introduction in 1981, the US $1,795 price of the Osborne 1 and its competitor Kaypro was considered an attractive price point; these systems had text-only displays and only floppy disks for storage. By 1982, Michael Dell observed that a personal computer system selling at retail for about $3,000 US was made of components that cost the dealer about $600; typical gross margin on a computer unit was around $1,000.[45] The total value of personal computer purchases in the US in 1983 was about $4 billion, comparable to total sales of pet food. By late 1998, the average selling price of personal computer systems in the United States had dropped below $1,000.[46]

For Microsoft Windows systems, the average selling price (ASP) showed a decline in 2008/2009, possibly due to low-cost netbooks, drawing $569 for desktop computers and $689 for laptops at U.S. retail in August 2008. In 2009, ASP had further fallen to $533 for desktops and to $602 for notebooks by January and to $540 and $560 in February.[47] According to research firm NPD, the average selling price of all Windows portable PCs has fallen from $659 in October 2008 to $519 in October 2009.[48]

3.2 Terminology

"PC" is an initialism for "personal computer". However, it is sometimes used in a different sense, referring to a personal computer with an Intel x86-compatible processor, very often running (but not necessarily limited to) Microsoft Windows, which is a combination sometimes also called Wintel, although large portion of PCs are not shipped with preinstalled Windows operating systems. Some PCs, including the OLPC XOs, are equipped with x86 or x64 processors but not designed to run Microsoft Windows. "PC" is used in contrast with "Mac", an Apple Macintosh computer.[49][50][51][52] This sense of the word is used in the *Get a Mac* advertisement campaign that ran between 2006 and 2009, as well as its rival, *I'm a PC* campaign, that appeared in 2008. Since Apple's transition to Intel processors starting 2005, all Macintosh computers are now PCs.[53]

3.3 Types

3.3.1 Stationary

Workstation

Sun SPARCstation 1+ from the early 1990s, with a 25 MHz RISC processor

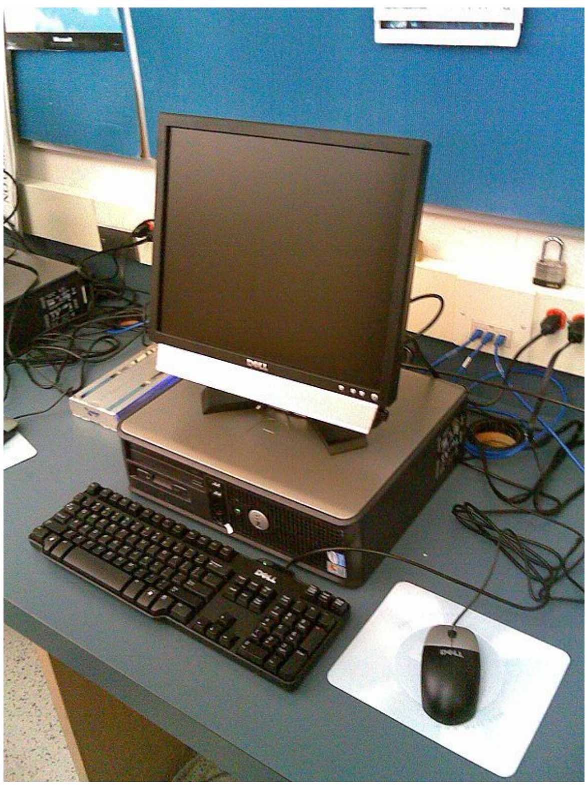
Main article: Workstation

A workstation is a high-end personal computer designed for technical, mathematical, or scientific applications. Intended primarily to be used by one person at a time, they are commonly connected to a local area network and run multi-user operating systems. Workstations are used for tasks such as computer-aided design, drafting and modeling, computation-intensive scientific and engineering calculations, image processing, architectural modeling, and computer graphics for animation and motion picture visual effects.[54]

Desktop computer

Main article: Desktop computer

Prior to the widespread usage of PCs, a computer that could fit on a desk was remarkably small, leading to the "desktop" nomenclature. More recently, the phrase usually indicates a particular style of computer case. Desktop computers come in a variety of styles ranging from large vertical tower cases to small models which can be tucked behind an LCD monitor. In this sense, the term "desktop" refers specifically to a horizontally oriented case, usually intended to have the display screen placed on top to save desk space. Most modern desktop computers have separate screens and keyboards.



A Dell OptiPlex desktop computer

Gaming computer Main article: Gaming computer

A gaming computer is a standard desktop computer that typically has high-performance hardware, such as a more powerful video card, processor and memory, in order to handle the requirements of demanding video games, which are often simply called "PC games".[55] A number of companies, such as Alienware, manufacture prebuilt gaming computers, and companies such as Razer and Logitech market mice, keyboards and headsets geared toward gamers.

Single unit Further information: All-in-one computer

Single-unit PCs (also known as all-in-one PCs) are a subtype of desktop computers that combine the monitor and case of the computer within a single unit. The monitor often utilizes a touchscreen as an optional method of user input, but separate keyboards and mice are normally still included. The inner components of the PC are often located directly behind the monitor and many of such PCs are built similarly to laptops.

Nettop

Main article: Nettop

A subtype of desktops, called nettops, was introduced by Intel in February 2008, characterized by low cost and lean functionality. A similar subtype of laptops (or notebooks) is the netbook, described below. The product line features the new Intel Atom processor, which specifically enables nettops to consume less power and fit into small enclosures.

Home theater PC

Main article: Home theater PC

A home theater PC (HTPC) is a convergence device that combines the functions of a personal computer and a digital video recorder. It is connected to a TV set or an appropriately sized computer display, and is often used as a digital photo viewer, music and video player, TV receiver, and digital video recorder. HTPCs are also referred to as media center systems or media servers. The general goal in a HTPC is usually to combine many or all components of a home theater setup into one box. More recently, HTPCs gained the ability to connect to services providing on-demand movies and TV shows.

HTPCs can be purchased pre-configured with the required hardware and software needed to add television programming to the PC, or can be cobbled together out of discrete components, what is commonly done with software

An Antec Fusion V2 home theater PC, with a keyboard placed on top of it.

support from MythTV, Windows Media Center, GB-PVR, SageTV, Famulent or LinuxMCE.

3.3.2 Portable

Laptop

Main article: Laptop

A laptop computer, also called a notebook, is a small per-

A modern laptop computer

sonal computer designed for portability. Usually, all of the hardware and interfaces needed to operate a laptop, such as the graphics card, audio devices or USB ports (previously parallel and serial ports), are built into a single unit. Laptops contain high-capacity batteries that can power the device for extensive periods of time, enhancing portability. Once the battery charge is depleted, it will have to be recharged through a power outlet. In the interests of saving power, weight and space, laptop graphics cards are in many cases integrated into the CPU or chipset and use system RAM, resulting in reduced graphics performance when compared to an equivalent desktop machine. For this reason, desktop or gaming computers are usually preferred to laptop PCs for gaming purposes.

One of the drawbacks of laptops is that, due to the size and configuration of components, usually relatively little can be done to upgrade the overall computer from its original design. Internal upgrades are either not manufacturer-recommended, can damage the laptop if done with poor care or knowledge, or in some cases impossible, making the desktop PC more modular. Some internal upgrades, such as memory and hard disk drive upgrades are often easily performed, while a display or keyboard upgrade is usually impossible. Just as desktops, laptops also have the same possibilities for connecting to a wide variety of devices, including external displays, mice, cameras, storage devices and keyboards, which may be attached externally through USB ports and other less common ports such as external video. Laptops are also a little more expensive compared to desktops, as the components for laptops themselves are expensive.

A subtype of notebooks, called subnotebook, has most of the features of a standard laptop computer, but with smaller physical dimensions. Subnotebooks are larger than handheld computers, and usually run full versions of desktop or laptop operating systems. Ultra-Mobile PCs (UMPC) are usually considered subnotebooks, or more specifically, subnotebook tablet PCs, which are described below. Netbooks are sometimes considered to belong to this category, though they are sometimes separated into a category of their own (see below).

Desktop replacement Main article: Desktop replacement computer

A desktop replacement computer (DTR) is a personal com-

An Acer Aspire desktop replacement laptop puter that provides the full capabilities of a desktop computer while remaining mobile. Such computers are often actually larger, bulkier laptops. Because of their increased size, this class of computers usually includes more powerful components and a larger display than generally found in smaller portable computers, and can have a relatively limited battery capacity or none at all in some cases. Some use a limited range of desktop components to provide better performance at the expense of battery life. Desktop replacement computers are sometimes called *desknotes*, as a portmanteau of words "desktop" and "notebook," though the term is also applied to desktop replacement computers in general.[56]

Netbook

Main article: Netbook

Netbooks, also called mini notebooks or subnotebooks,

An HP netbook

are a subgroup of laptops[57] acting as a category of small, lightweight and inexpensive laptop computers suited for general computing tasks and accessing web-based applications. They are often marketed as "companion devices", with an intention to augment other ways in which a user can access computer resources.[57] Walt Mossberg called them a "relatively new category of small, light, minimalist and cheap laptops."[58] By August 2009, CNET called netbooks "nothing more than smaller, cheaper notebooks."[57]

Initially, the primary defining characteristic of netbooks was the lack of an optical disc drive, requiring it to be a separate external device. This has become less important as flash memory devices have gradually increased in capacity, replacing the writable optical disc (e.g. CD-RW, DVD-RW) as a transportable storage medium.

At their inception in late 2007—as smaller notebooks optimized for low weight and low cost[59]—netbooks omitted key features (e.g., the optical drive), featured smaller screens and keyboards, and offered reduced specifications and computing power. Over the course of their evolution, netbooks have ranged in their screen sizes from below five inches[60] to over 13 inches,[61] with weights around ~1 kg (2-3 pounds). Often significantly less expensive than other laptops,[62] by mid-2009 netbooks had been offered to users "free of charge", with an extended service contract purchase of a cellular data plan.[63]

In the short period since their appearance, netbooks have grown in size and features, converging with new smaller and lighter notebooks. By mid-2009, CNET noted that "the specs are so similar that the average shopper would likely be confused as to why one is better than the other," noting "the only conclusion is that there really is no distinction between the devices."[57]

Tablet

Main article: Tablet computer

A tablet is a type of portable PC that de-emphasizes the use

HP Compaq tablet PC with rotating/removable keyboard

of traditional input devices (such as a mouse or keyboard) by using a touchscreen display, which can be controlled using either a stylus pen or finger. Some tablets may use a "hybrid" or "convertible" design, offering a keyboard that can either be removed as an attachment, or a screen that can be rotated and folded directly over top the keyboard.

Some tablets may run a traditional PC operating system such as Windows or Linux; Microsoft attempted to enter the tablet market in 2002 with its Microsoft Tablet PC specifications, for tablets and convertible laptops running Windows XP. However, Microsoft's early attempts were overshadowed by the release of Apple's iPad; following in its footsteps, most modern tablets use slate designs and run mobile operating systems such as Android and iOS, giving them functionality similar to smartphones. In response, Microsoft built its Windows 8 operating system to better accommodate these new touch-oriented devices.[64] Many tablet computers have USB ports, to which a keyboard or mouse can be connected.

Ultra-mobile PC

Main article: Ultra-mobile PC

The ultra-mobile PC (UMPC) is a specification for small-

A Samsung Q1 ultra-mobile PC

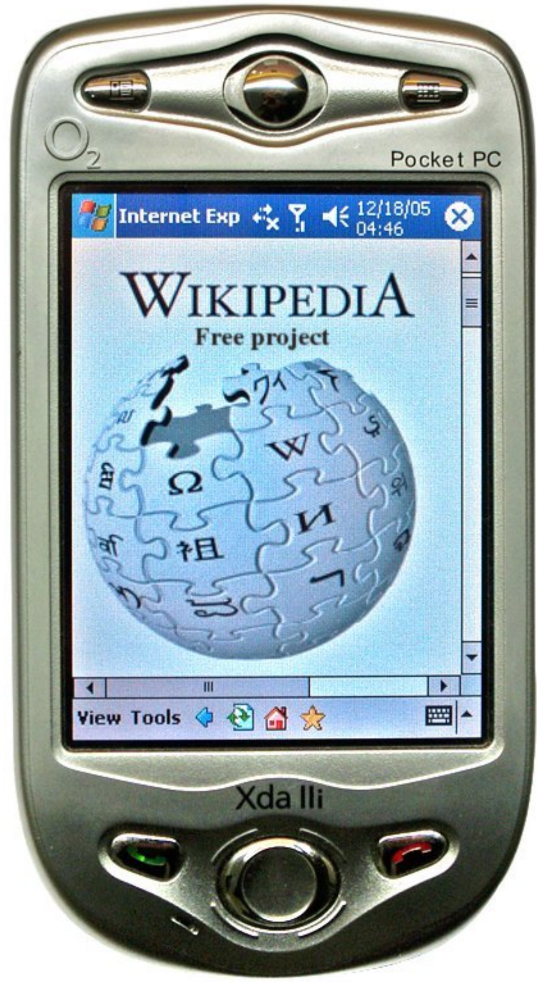
configuration tablet PCs. It was developed as a joint development exercise by Microsoft, Intel and Samsung, among others. Current UMPCs typically feature the Windows XP, Windows Vista, Windows 7, or Linux operating system, and low-voltage Intel Atom or VIA C7-M processors.

Pocket PC

Main article: Pocket PC

A pocket PC is a hardware specification for a handheld-sized computer (personal digital assistant, PDA) that runs the Microsoft Windows Mobile operating system. It may have the capability to run an alternative operating system like NetBSD or Linux. Pocket PCs have many of the capabilities of modern desktop PCs.

Numerous applications are available for handhelds adhering to the Microsoft Pocket PC specification, many of which are freeware. Some of these devices also include mobile phone features, actually representing a smartphone. Microsoft-compliant Pocket PCs can also be used with many other add-ons like GPS receivers, barcode readers,



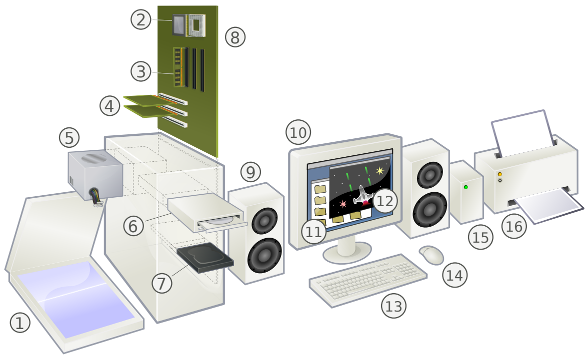
An O_2 pocket PC

RFID readers and cameras. In 2007, with the release of Windows Mobile 6, Microsoft dropped the name Pocket PC in favor of a new naming scheme: devices without an integrated phone are called Windows Mobile Classic instead of Pocket PC, while devices with an integrated phone and a touch screen are called Windows Mobile Professional.[65]

3.4 Hardware

Main article: Personal computer hardware

Computer hardware is a comprehensive term for all physical parts of a computer, as distinguished from the data it contains or operates on, and the software that provides instructions for the hardware to accomplish tasks. The boundary between hardware and software might be slightly blurry,



An exploded view of a modern personal computer and peripherals:

1. *Scanner*
2. *CPU (Microprocessor)*
3. *Memory (RAM)*
4. *Expansion cards (graphics cards, etc.)*
5. *Power supply*
6. *Optical disc drive*
7. *Storage (Hard disk or SSD)*
8. *Motherboard*
9. *Speakers*
10. *Monitor*
11. *System software*
12. *Application software*
13. *Keyboard*
14. *Mouse*
15. *External hard disk*
16. *Printer*

with the existence of firmware that is software "built into" the hardware.

Mass-market consumer computers use highly standardized components and so are simple for an end user to assemble into a working system. A typical desktop computer consists of a computer case that holds the power supply, motherboard, hard disk drive, and often an optical disc drive. External devices such as a computer monitor or visual display unit, keyboard, and a pointing device are usually found in a personal computer.

The motherboard connects all processor, memory and peripheral devices together. The RAM, graphics card and processor are in most cases mounted directly onto the motherboard. The central processing unit (microprocessor chip) plugs into a CPU socket, while the memory modules plug into corresponding memory sockets. Some motherboards have the video display adapter, sound and other peripherals integrated onto the motherboard, while others use expansion slots for graphics cards, network cards, or other I/O devices. The graphics card or sound card may employ a break out box to keep the analog parts away from the electromagnetic radiation inside the computer case. Disk drives, which provide mass storage, are connected to the motherboard with one cable, and to the power supply through another cable. Usually, disk drives are mounted in the same case as the motherboard; expansion chassis are also made for additional disk storage. For extended amounts of data, a tape drive can be used or extra hard disks can be put together in an external case.

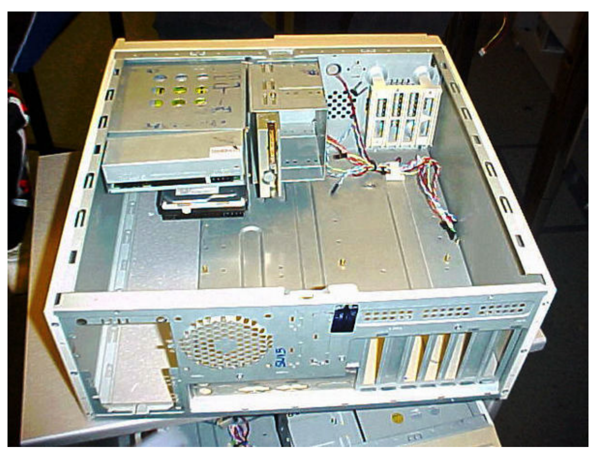
The keyboard and the mouse are external devices plugged into the computer through connectors on an I/O panel on the back of the computer case. The monitor is also connected to the I/O panel, either through an onboard port on the motherboard, or a port on the graphics card.

Capabilities of the personal computers hardware can sometimes be extended by the addition of expansion cards connected via an expansion bus. Standard peripheral buses often used for adding expansion cards in personal computers include PCI, PCI Express (PCIe), and AGP (a high-speed PCI bus dedicated to graphics adapters, found in older computers). Most modern personal computers have multiple physical PCI Express expansion slots, with some of the having PCI slots as well.

3.4.1 Computer case

Main article: Computer case

A computer case is an enclosure that contains the main components of a computer. They are usually constructed from steel or aluminum combined with plastic, although other materials such as wood have been used. Cases are available in different sizes and shapes; the size and shape



A stripped ATX case lying on its side.

of a computer case is usually determined by the configuration of the motherboard that it is designed to accommodate, since this is the largest and most central component of most computers.

The most popular style for desktop computers is ATX, although microATX and similar layouts became very popular for a variety of uses. Companies like Shuttle Inc. and AOpen have popularized small cases, for which FlexATX is the most common motherboard size.

3.4.2 Power supply unit

Main article: Power supply unit (computer)

The power supply unit (PSU) converts general-purpose

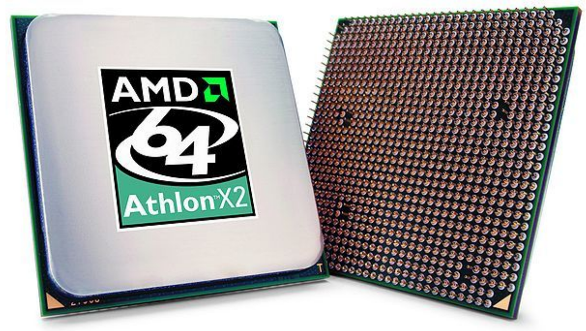
Computer power supply unit with top cover removed.

mains AC electricity to direct current (DC) for the other components of the computer. The rated output capacity of a PSU should usually be about 40% greater than the calculated system power consumption needs obtained by adding up all the system components. This protects against overloading the supply, and guards against performance degradation.

3.4.3 Processor

Main article: Central processing unit

The central processing unit, or CPU, is a part of a computer that executes instructions of a software program. In newer PCs, the CPU contains over a million transistors in one integrated circuit chip called the microprocessor. In most cases, the microprocessor plugs directly into the motherboard. The chip generates so much heat that the PC builder



AMD Athlon 64 X2 CPU.

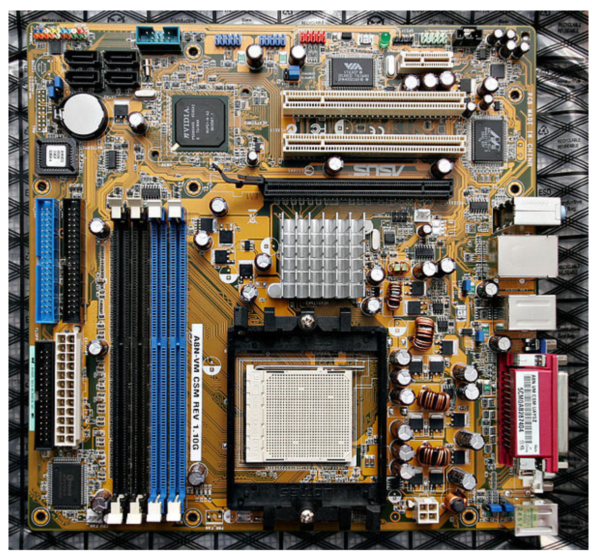
is required to attach a special cooling device to its surface; thus, modern CPUs are equipped with a fan attached via heat sink.

IBM PC compatible computers use an x86-compatible microprocessor, manufactured by Intel, AMD, VIA Technologies or Transmeta. Apple Macintosh computers were initially built with the Motorola 680x0 family of processors, then switched to the PowerPC series; in 2006, they switched to x86-compatible processors made by Intel.

3.4.4 Motherboard

Main article: Motherboard

The motherboard, also referred to as system board or main



A motherboard without processor, memory and expansion cards, cables

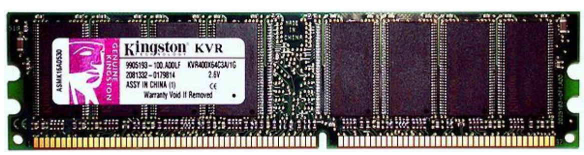
board, is the primary circuit board within a personal computer, and other major system components plug directly into it or via a cable. A motherboard contains a microprocessor, the CPU supporting circuitry (mostly integrated circuits) that provide the interface between memory and input/output peripheral circuits, main memory, and facilities for initial setup of the computer immediately after power-on (often called boot firmware or, in IBM PC compatible computers, a BIOS or UEFI).

In many portable and embedded personal computers, the motherboard houses nearly all of the PC's core components. Often a motherboard will also contain one or more peripheral buses and physical connectors for expansion purposes. Sometimes a secondary daughter board is connected to the motherboard to provide further expandability or to satisfy space constraints.

3.4.5 Main memory

Main article: Primary storage

A PC's main memory is a fast primary storage device that



1GB DDR SDRAM PC-3200 module

is directly accessible by the CPU, and is used to store the currently executing program and immediately needed data. PCs use semiconductor random access memory (RAM) of various kinds such as DRAM, SDRAM or SRAM as their primary storage. Which exact kind is used depends on cost/performance issues at any particular time.

Main memory is much faster than mass storage devices like hard disk drives or optical discs, but is usually volatile, meaning that it does not retain its contents (instructions or data) in the absence of power, and is much more expensive for a given capacity than is most mass storage. As a result, main memory is generally not suitable for long-term or archival data storage.

3.4.6 Hard disk

A Western Digital 250 GB hard disk drive

Main article: Hard disk drive

Mass storage devices store programs and data even when the power is off; they do require power to perform read and write functions during usage. Although flash memory has dropped in cost, the prevailing form of mass storage in personal computers is still the hard disk drive.

If the mass storage controller provides additional ports for expandability, a PC may also be upgraded by the addition of extra hard disk or optical disc drives. For example, BD-ROMs, DVD-RWs, and various optical disc recorders may all be added by the user to certain PCs. Standard internal storage device connection interfaces are PATA, Serial ATA and SCSI.

Solid state drives (SSDs) are a much faster replacement for traditional mechanical hard disk drives, but are also more expensive in terms of cost per gigabyte.

3.4.7 Visual display unit

Main article: Visual display unit

A visual display unit, computer monitor or just display, is a piece of electrical equipment, usually separate from the computer case, which displays visual images without producing a permanent computer record. A display device is usually either a CRT or some form of flat panel such as a TFT LCD. Multi-monitor setups are also quite common.

The display unit houses an electronic circuitry that generates its picture from signals received from the computer. Within the computer, either integral to the motherboard or plugged into it as an expansion card, there is pre-processing circuitry to convert the microprocessor's output data to a format compatible with the display unit's circuitry. The images from computer monitors originally contained only text, but as graphical user interfaces emerged and became common, they began to display more images and multimedia content.

The term "monitor" is also used, particularly by technicians in broadcasting television, where a picture of the broadcast data is displayed to a highly standardized reference monitor for confidence checking purposes.

3.4.8 Video card

Main article: Video card

The video card—otherwise called a graphics card, graph-

An ATI Radeon video card

ics adapter or video adapter—processes the graphics output from the motherboard and transmits it to the display. It is an essential part of modern multimedia-enriched computing. On older models, and today on budget models, graphics circuitry may be integrated with the motherboard, but for modern and flexible machines, they are connected by the PCI, AGP, or PCI Express interface.

When the IBM PC was introduced, most existing business-oriented personal computers used text-only display adapters and had no graphics capability. Home computers at that time had graphics compatible with television signals, but with low resolution by modern standards owing to the limited memory available to the eight-bit processors available at the time.

3.4.9 Keyboard

Main article: Keyboard (computing)

A keyboard is an arrangement of buttons that each corre-

A "Model M" IBM computer keyboard from the early 1980s. Commonly called the "Clicky Keyboard" due to its buckling spring key spring design, which gives the keyboard its iconic 'Click' sound with each keystroke.

spond to a function, letter, or number. They are the primary devices used for inputting text. In most cases, they contain an array of keys specifically organized with the corresponding letters, numbers, and functions printed or engraved on the button. They are generally designed around an operators language, and many different versions for different languages exist.

In English, the most common layout is the QWERTY layout, which was originally used in typewriters. They have evolved over time, and have been modified for use in computers with the addition of function keys, number keys, arrow keys, and keys specific to an operating system. Often, specific functions can be achieved by pressing multiple keys at once or in succession, such as inputting characters with accents or opening a task manager. Programs use keyboard shortcuts very differently and all use different keyboard shortcuts for different program specific operations, such as refreshing a web page in a web browser or selecting all text in a word processor.

3.4.10 Mouse

Main article: Mouse (computing)

A computer mouse is a small handheld device that users

A selection of computer mice built between 1986 and 2007

hold and slide across a flat surface, pointing at various elements of a graphical user interface with an on-screen cursor, and selecting and moving objects using the mouse buttons. Almost all modern personal computers include a mouse; it may be plugged into a computer's rear mouse socket, or as a USB device, or, more recently, may be connected wirelessly via an USB dongle or Bluetooth link.

In the past, mice had a single button that users could press down on the device to "click" on whatever the pointer on the screen was hovering over. Modern mice have two, three or more buttons, providing a “right click” function button on the mouse, which performs a secondary action on a selected object, and a scroll wheel, which users can rotate using their fingers to “scroll” up or down. The scroll wheel can also be pressed down, and therefore be used as a third button. Some mouse wheels may be tilted from side to side to allow sideways scrolling. Different programs make use of these functions differently, and may scroll horizontally by default with the scroll wheel, open different menus with different buttons, etc. These functions may be also user-defined through software utilities.

Mice traditionally detected movement and communicated with the computer with an internal “mouse ball”, and used optical encoders to detect rotation of the ball and tell the computer where the mouse has moved. However, these systems were subject to low durability, accuracy and required internal cleaning. Modern mice use optical technology to directly trace movement of the surface under the mouse and are much more accurate, durable and almost maintenance free. They work on a wider variety of surfaces and can even operate on walls, ceilings or other non-horizontal surfaces.

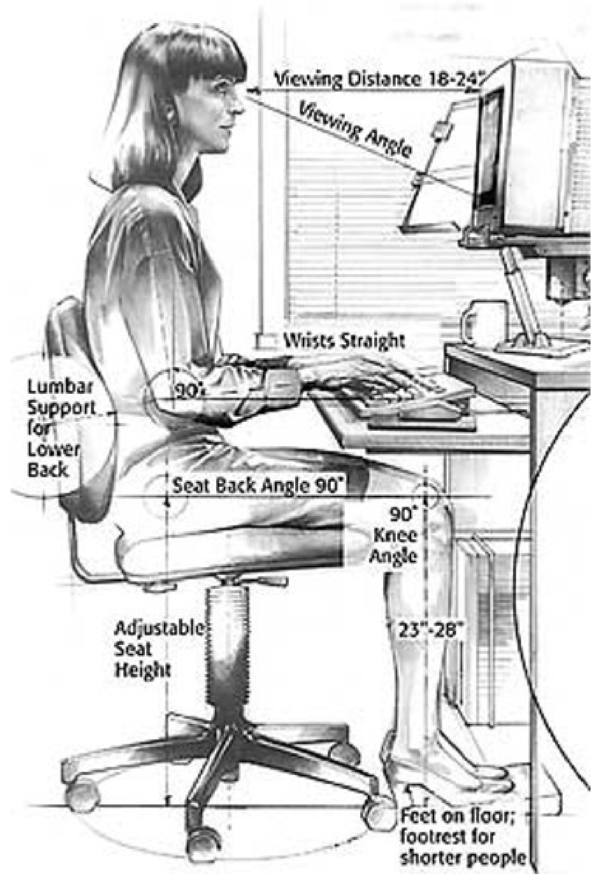
3.4.11 Other components

All computers require either fixed or removable storage for their operating system, programs and user-generated material. Early home computers used compact audio cassettes for file storage; these were at the time a very low cost storage solution, but were displaced by floppy disk drives when manufacturing costs dropped, by the mid-1980s.

Initially, the 5.25-inch and 3.5-inch floppy drives were the principal forms of removable storage for backup of user files and distribution of software. As memory sizes increased, the capacity of the floppy did not keep pace; the Zip drive and other higher-capacity removable media were introduced but never became as prevalent as the floppy drive.

By the late 1990s, the optical drive, in CD and later DVD and Blu-ray Disc forms, became the main method for software distribution, and writeable media provided means for data backup and file interchange. As a result, floppy drives became uncommon in desktop personal computers since about 2000, and were dropped from many laptop systems even earlier.[note 1]

A second generation of tape recorders was provided when videocassette recorders were pressed into service as backup media for larger disk drives. All these systems were less reliable and slower than purpose-built magnetic tape drives. Such tape drives were uncommon in consumer-type personal computers but were a necessity in business or industrial use.



A proper ergonomic design of a personal computer workplace is necessary to prevent repetitive strain injuries, which can develop over time and can lead to long-term disability.[66]

Interchange of data such as photographs from digital cameras is greatly expedited by installation of a card reader, which is often compatible with several forms of flash memory devices. It is usually faster and more convenient to move large amounts of data by removing the card from the mobile device, instead of communicating with the mobile device through a USB interface.

A USB flash drive performs much of the data transfer and backup functions formerly done with floppy drives, Zip disks and other devices. Mainstream operating systems for personal computers provide built-in support for USB flash drives, allowing interchange even between computers with different processors and operating systems. The compact size and lack of moving parts or dirt-sensitive media, combined with low cost and high capacity, have made USB flash drives a popular and useful accessory for any personal computer user.

The operating system can be located on any storage, but is typically installed on a hard disk or solid-state drive. A Live

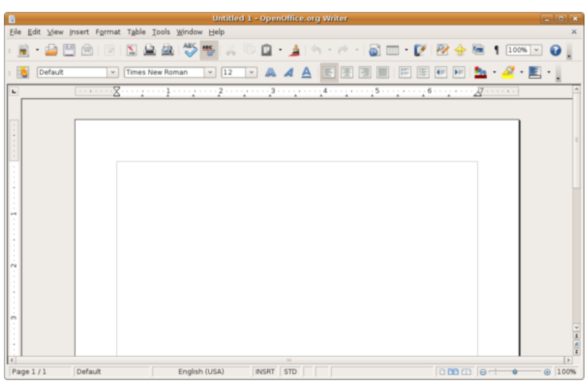
CD represents the concept of running an operating system directly from a CD. While this is slow compared to storing the operating system on a hard disk drive, it is typically used for installation of operating systems, demonstrations, system recovery, or other special purposes. Large flash memory is currently more expensive than hard disk drives of similar size (as of mid-2014) but are starting to appear in laptop computers because of their low weight, small size and low power requirements.

Computer communications involve internal modem cards, modems, network adapter cards, and routers. Common peripherals and adapter cards include headsets, joysticks, microphones, printers, scanners, sound adapter cards (as a separate card rather than located on the motherboard), speakers and webcams.

3.5 Software

Main article: Computer software

Computer software is any kind of computer program,



A screenshot of the OpenOffice.org Writer software

procedure, or documentation that performs some task on a computer system.[67] The term includes application software such as word processors that perform productive tasks for users, system software such as operating systems that interface with computer hardware to provide the necessary services for application software, and middleware that controls and co-ordinates distributed systems.

Software applications are common for word processing, Internet browsing, Internet faxing, e-mail and other digital messaging, multimedia playback, playing of computer game, and computer programming. The user of a modern personal computer may have significant knowledge of the operating environment and application programs, but is not necessarily interested in programming nor even able to write programs for the computer. Therefore, most software written primarily for personal computers tends to be designed with simplicity of use, or "user-friendliness" in mind. However, the software industry continuously provide a wide range of new products for use in personal computers, targeted at both the expert and the non-expert user.

3.5.1 Operating system

Main article: Operating system
See also: Usage share of operating systems

An operating system (OS) manages computer resources and provides programmers with an interface used to access those resources. An operating system processes system data and user input, and responds by allocating and managing tasks and internal system resources as a service to users and programs of the system. An operating system performs basic tasks such as controlling and allocating memory, prioritizing system requests, controlling input and output devices, facilitating computer networking, and managing files.

Common contemporary desktop operating systems are Microsoft Windows, OS X, Linux, Solaris and FreeBSD. Windows, OS X, and Linux all have server and personal variants. With the exception of Microsoft Windows, the designs of each of them were inspired by or directly inherited from the Unix operating system, which was developed at Bell Labs beginning in the late 1960s and spawned the development of numerous free and proprietary operating systems.

Microsoft Windows

Main article: Microsoft Windows

Microsoft Windows is the collective brand name of several operating systems made by Microsoft which, as of 2015, are installed on PCs built by HP, Dell and Lenovo, the three remaining high volume manufacturers.[68] Microsoft first introduced an operating environment named Windows in November 1985,[69] as an add-on to MS-DOS and in response to the growing interest in graphical user interfaces (GUIs)[70][71] generated by Apple's 1984 introduction of the Macintosh.[72] As of August 2015, the most recent client and server version of Windows are Windows 10 and Windows Server 2012 R2, respectively. Windows Server 2016 is currently in Beta Testing.

OS X

Main article: OS X

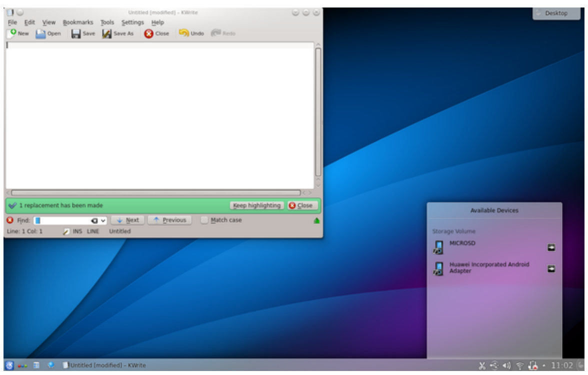
OS X (formerly Mac OS X) is a line of operating systems developed, marketed and sold by Apple Inc.. OS X is the successor to the original Mac OS, which had been Apple's primary operating system since 1984. OS X is a Unix-based graphical operating system, and Snow Leopard, Leopard, Lion, Mountain Lion, Mavericks and Yosemite are its version codenames. The most recent version of OS X is codenamed El Capitan.

On iPhone, iPad and iPod, versions of iOS (which is an OS X derivative) are available from iOS 1.0 to the recent iOS 9. The iOS devices, however, are not considered PCs.

Linux

Main article: Linux

Linux is a family of Unix-like computer operating systems.



A Linux distribution running KDE Plasma Workspaces 4.

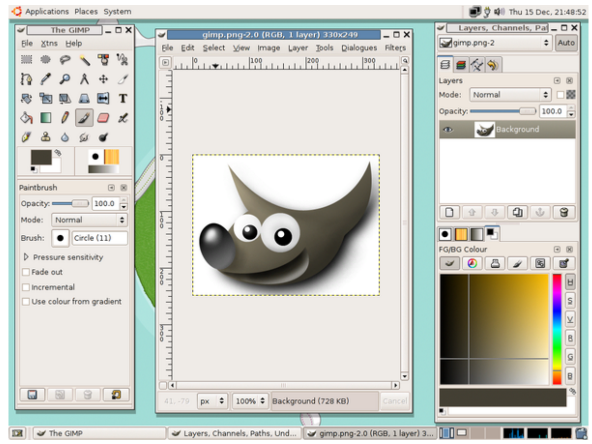
Linux is one of the most prominent examples of free software and open source development: typically all underlying source code can be freely modified, used, and redistributed by anyone.[73] The name "Linux" refers to the Linux kernel, started in 1991 by Linus Torvalds. The system's utilities and libraries usually come from the GNU operating system, announced in 1983 by Richard Stallman. The GNU contribution is the basis for the alternative name GNU/Linux.[74]

Known for its use in servers, with the LAMP application stack as one of prominent examples, Linux is supported by corporations such as Dell, Hewlett-Packard, IBM, Novell, Oracle Corporation, Red Hat, Canonical Ltd. and Sun Microsystems. It is used as an operating system for a wide variety of computer hardware, including desktop computers, netbooks, supercomputers,[75] video game systems such as the Steam Machine or PlayStation 3 (until this option was removed remotely by Sony in 2010[76]), several arcade games, and embedded devices such as mobile phones, portable media players, routers, and stage lighting systems.

3.5.2 Applications

Main article: Application software

Generally, a computer user uses application software to



A screenshot of GIMP, which is a raster graphics editor

carry out a specific task. System software supports applications and provides common services such as memory management, network connectivity and device drivers, all of which may be used by applications but are not directly of interest to the end user. A simplified analogy in the world of hardware would be the relationship of an electric light bulb (an application) to an electric power generation plant (a system): the power plant merely generates electricity, not itself of any real use until harnessed to an application like the electric light that performs a service that benefits the user.

Typical examples of software applications are word processors, spreadsheets, and media players. Multiple applications bundled together as a package are sometimes referred to as an *application suite*. Microsoft Office and OpenOffice.org, which bundle together a word processor, a spreadsheet, and several other discrete applications, are typical examples. The separate applications in a suite usually have a user interface that has some commonality making it easier for the user to learn and use each application. Often, they may have some capability to interact with each other in ways beneficial to the user; for example, a spreadsheet might be able to be embedded in a word processor document even though it had been created in the separate spreadsheet application.

End-user development tailors systems to meet the user's specific needs. User-written software include spreadsheet templates, word processor macros, scientific simulations, graphics and animation scripts; even email filters are a kind of user software. Users create this software themselves and often overlook how important it is.

3.5.3 Gaming

PC gaming is popular among the high-end PC market. According to an April 2014 market analysis, Gaming platforms like Steam (software), Uplay, Origin, and GOG.com (as well as competitive e-sports titles like League of Legends) are largely responsible for PC systems overtaking console revenue in 2013.[77]

3.6 Toxicity

Toxic chemicals found in some computer hardware include lead, mercury, cadmium, chromium, plastic (PVC), and barium. Overall, a computer is about 17% lead, copper, zinc, mercury, and cadmium; 23% is plastic, 14% is aluminum, and 20% is iron.

Lead is found in a cathode ray tube (CRT) display, and on all of the printed circuit boards and most expansion cards. Mercury is located in the screen's fluorescent lamp, in the laser light generators in the optical disk drive, and in the round, silver-looking batteries on the motherboard. Plastic is found mostly in the housing of the computation and display circuitry.

While daily end-users are not exposed to these toxic elements, the danger arises during the computer recycling process, which involves manually breaking down hardware and leads to the exposure of a measurable amount of lead or mercury. A measurable amount of lead or mercury can easily cause serious brain damage or ruin drinking water supplies. Computer recycling is best handled by the electronic waste (e-waste) industry, and kept segregated from the general community dump.

3.6.1 Electronic waste regulation

Main article: Computer recycling

Personal computers have become a large contributor to the 50 million tons of discarded electronic waste that is being generated annually, according to the United Nations Environment Programme. To address the electronic waste issue affecting developing countries and the environment, extended producer responsibility (EPR) acts have been implemented in various countries and states.[78]

Organizations, such as the Silicon Valley Toxics Coalition, Basel Action Network, Toxics Link India, SCOPE, and Greenpeace have contributed to these efforts. In the absence of comprehensive national legislation or regulation on the export and import of electronic waste, the Silicon Valley Toxics Coalition and BAN (Basel Action Network) teamed up with 32 electronic recyclers in the US and Canada to create an e-steward program for the orderly disposal of manufacturers and customers electronic waste. The Silicon Valley Toxics Coalition founded the Electronics TakeBack Coalition, a coalition that advocates for the production of environmentally friendly products. The TakeBack Coalition works with policy makers, recyclers, and smart businesses to get manufacturers to take full responsibility of their products.

There are organizations opposing EPR regulation, such as the Reason Foundation. They see flaws in two principal tenants of EPR: First EPR relies on the idea that if the manufacturers have to pay for environmental harm, they will adapt their practices. Second EPR assumes the current design practices are environmentally inefficient. The Reason Foundation claims that manufacturers naturally move toward reduced material and energy use.

3.7 See also

- Computer case
- Computer virus
- Desktop computer
- Desktop replacement computer
- e-waste
- IBM 5100
- Information and communication technologies for development
- Laptop
- List of computer system manufacturers
- Market share of personal computer vendors
- Personal Computer Museum
- Portable computer
- Public computer
- Quiet PC
- PC game

3.8 Notes

[1] The NeXT computer introduced in 1988 did not include a floppy drive, which at the time was unusual.

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3.10 Further reading

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3.11 External links

- How Stuff Works pages:
  - Dissecting a PC
  - How PCs Work
  - How to Upgrade Your Computer
  - How to Build a Computer

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