

DIGITAL COMPUTERS: HISTORY

ORIGINS

Mechanical aids to calculation and mechanical sequence-control devices were perhaps the earliest and most important achievements in the development of computer technology.

The first adding machines date from the early seventeenth century, the most famous of which was invented by the French scientist and philosopher Blaise Pascal, although it is now believed that his work was predated by that of William Schickard. A number of Pascal's machines, which he started to build in 1642, still exist. Even though he had intended them for practical use, their unreliability caused them to be treated mainly as objects of scientific curiosity. During the subsequent two centuries, numerous attempts to develop practical calculating machines were made by Morland, Leibniz, Mahon, Hahn, and Müller, among others. However, it was not until the mid-nineteenth century that a commercially successful machine was produced. This was the "arithmometer" of Thomas de Colmar, the first version of which was invented in 1820, and which used the stepped-wheel mechanism invented by Leibniz.

Mechanical devices for controlling the sequencing of a set of operations, such as the rotating pegged cylinders still seen in music boxes today, date back even earlier. For example, de Caus (1576-1626) used such a mechanism to control both the playing of an organ and the movements of model figures. One of the most famous designers of mechanical automata was Vaucanson. In 1736, he successfully demonstrated an automaton that simulated human lip and finger movements with sufficient accuracy to play a flute. Vaucanson was also involved in the development of what came to be known as the Jacquard loom, in which the woven pattern was specified and controlled by a sequence of perforated cards. The original idea can be traced back to Bouchon in 1725, but such automatic looms did not come into widespread use until early in the nineteenth century after the work by Jacquard.

In 1834, these two lines of development came together in the work of Charles Babbage, who had become dissatisfied with the accuracy of printed mathematical tables. Earlier, in 1822, Babbage had built a small machine, involving several linked adding mechanisms, which would automatically generate successive values of simple algebraic functions using the method of finite differences. His attempt at making a full-scale model with a printing mechanism was abandoned in 1834, and he then started to design a more versatile machine. In the space of a few years he had developed the concept of a program-controlled, mechanical, digital computer, incorporating a complete arithmetic unit, store, punched-card input and output, and printing mechanism. The machine, which he called an analytical engine, was to have been controlled by programs represented by sets of Jacquard cards, with conditional jumps and iteration loops being provided for by devices that skipped forward or backward over the required number of cards. Internally, the machine was essentially microprogrammed by rotating pegged cylinders that controlled the sequencing of subsidiary mechanisms.

Babbage's work inspired several other people, among whom were Ludgate, who designed an analytical engine in Ireland in 1909; Torres y Quevedo, who demonstrated the feasibility of an electromechanical analytical engine by successfully producing a typewriter-controlled calculating machine in 1920; and Couffignal, who started to design a binary analytical engine in France during the 1930s. However, Babbage's pioneering efforts were apparently unknown to most of the people who worked on the various computer projects during World War II and who were unaware that the problems they were tackling had been considered and often solved by Babbage more than a hundred years earlier.

The Jacquard loom was perhaps the source of Herman Hollerith's idea of using punched cards to represent logical and numerical data. Developed for use in the 1890 U. S. National Census, his system, incorporating hand-operated

tabulating machines and sorters, was highly successful and spread rapidly to several other countries. Automatic card-feed mechanisms were soon provided, and the system began to be used for business accounting applications. Following a dispute with Hollerith, the Bureau of the Census developed in time for the 1910 Census a new tabulating system involving mechanical sensing of card perforations, as opposed to Hollerith's system of electrical sensing. James Powers, the engineer in charge of this work, eventually left the Bureau to form his own company, which later became part of Remington Rand. Hollerith's company merged with two others to become the Computing-Tabulating-Recording Company, which, in 1924, changed its name to the International Business Machines Corporation.

In 1937, Howard Aiken of Harvard University approached IBM with a proposal for a large-scale calculator to be built from the mechanical and electromechanical devices that were used for punched-card machines. The resulting machine, the Automatic Sequence Controlled Calculator, or Harvard Mark I, was built at the IBM Development Laboratories at Endicott. The machine, which was completed in 1943, was a huge affair with 72 decimal accumulators, capable of multiplying two 23-digit numbers in 6 sec. It was controlled by a sequence of instructions specified by a perforated paper tape; somewhat surprisingly, in view of Aiken's knowledge of and respect for Babbage's efforts, it lacked general conditional jump facilities. After completion of the Mark I, Aiken and IBM pursued separate paths. Several more machines were designed at Harvard, the first being another tape-controlled calculator, built this time from electromagnetic relays. IBM produced various machines, including several plug-board-controlled relay calculators and the partly electronic Selective Sequence Electronic Calculator, which was very much in the tradition of the original Mark I.

Not until well after World War II was it found that in Germany there had been an operational program-controlled calculator built earlier than the Mark I, namely, Konrad Zuse's Z3 machine, which first worked in 1941. This machine, which had been preceded by two earlier but unsuccessful machines, had a mechanical store, but was otherwise built from telephone relays. It could store 64 floating-point binary numbers, and has been described as somewhat faster than the Harvard Mark I. The Z3, like several other machines built by Zuse, did not survive the war; the only one of Zuse's machines to do so was the Z4 computer, which was later used successfully for several years at the Technische Hochschule in Zurich.

Various other electromechanical machines were built during and even after World War II, including an important series of relay calculators at the Bell Telephone Laboratories. The first of these, the Complex Computer, was demonstrated in September 1940 by being operated in its New York City location from a teletypewriter installed in Hanover, New Hampshire, on the occasion of a meeting of the American Mathematical Society. The Complex Computer, or Model 1, was capable of adding, subtracting, multiplying, and dividing two complex numbers, but lacked any sequence-control facilities. Later machines in the series incorporated successively more extensive sequencing facilities, so that the Model 5 relay calculator was a truly general-purpose (tape-controlled) computer that achieved very high reliability of operation.

The earliest known electronic digital calculating device was a machine for solving up to 30 simultaneous linear equations, initiated in 1938 at Iowa State College by John Atanasoff and Clifford Berry. Although the arithmetic unit had been successfully tested before the project was abandoned in 1942, the input/output mechanism was still incomplete, so the machine never saw actual use. Other important work on the development of electronic calculating devices was done at IBM, starting in 1942 with the building of experimental versions of various punched-card machines, including a multiplier. This machine was the origin of the electronic multipliers and calculating machines, such as the Type 604 and the Card Programmed Calculator (CPC), that IBM produced in great quantities in the years immediately following World War II and that played an important role until stored program electronic computers became widely available.

The earliest known efforts at applying electronics to a general-purpose, program-controlled computer were those undertaken by Schreyer and Zuse in 1939, but their plans for a 1,500-valve (i.e. vacuum tube) machine were later rejected by the German government. In Britain, a series of large special-purpose electronic computers, intended for code-breaking purposes, was developed by a team at Bletchley Park (where Alan Turing was a senior cryptanalyst), led by Tommy Flowers from the Post Office Research Station at Dollis Hill. The first of these “Colossus” machines, which incorporated about 2,000 tubes, was operating in December 1943. By the end of the war ten Colossi were in use, and had made a major contribution to the war by enabling the Allies to read large numbers of encrypted teleprinter messages to and from the German High Command. The Colossus has been described as being, in a very limited fashion, a program-controlled device. An exact working replica has now been created at Bletchley Park. Interestingly enough, several postwar British electronic computers were developed by people who had been involved with these highly secret machines.

However, by far the most influential line of development was that carried out at the Moore School of Electrical Engineering at the University of Pennsylvania by John Mauchly, J. Presper Eckert, and their colleagues, starting in 1943. This work, which derived at least as directly from Vannevar Bush’s prewar mechanical differential analyzer as from any digital calculating device, first led to the development of the ENIAC, which was officially inaugurated in February 1946. This machine was intended primarily for ballistics calculations, but by the time it was completed, it was really a general-purpose device, programmed by means of pluggable interconnections. Its internal electronic memory consisted of 20 accumulators, each of 10 decimal digits, and it could perform 5,000 arithmetic operations per second -- it was approximately a thousand times faster than the Harvard Mark I. The ENIAC was very much the most complex piece of electronic equipment that had ever been assembled, incorporating 19,000 tubes, and using nearly 200 KW of power. The machine was very successful, despite earlier fears regarding the reliability of electronic components.

But even before the ENIAC was complete, the designers, who had been joined by John von Neumann, started to plan a radically different successor machine, the EDVAC. The EDVAC was a serial binary machine, far more economical on electronic tubes than ENIAC, which was a decimal machine in which each decimal digit was represented by a ring of ten flip-flops. A second major difference was that EDVAC was to have a much larger internal memory than ENIAC, based on mercury delay lines. For these reasons, the initial design of EDVAC included only one-tenth of the equipment used in ENIAC, yet provided a hundred times the internal memory capacity.

It was apparently the discussions of the various ways in which the capabilities of ENIAC might be extended, together with the knowledge of the possibility of comparatively large internal memories, that led to the realization that sequence-control information could be represented by words held in memory along with the numerical quantities entering into the computation, rather than by some external means, such as perforated tape or pluggable interconnections. Thus, EDVAC could retain the great speed of operation that had been achieved by ENIAC, but could avoid the very lengthy setup time, often on the order of a day or more, that had made it impractical to use for other than very extensive calculations. The fact that a program could read and modify portions of itself was heavily utilized, since ideas such as index registers and indirect addresses were still in the offing. Of more lasting significance was the practical and attractive proposition of using the computer to assist with the preparation of its own programs.

With EDVAC, therefore, the invention of the modern digital computer was basically complete. The plans for its design were widely published and extremely influential, so that, even though it was not the first stored-program electronic digital computer to be put into operation, it undoubtedly was the major initial inspiration that started the vast number of computer projects during the late 1940s. A family tree depicting computer development up to the mid-1950s is shown in Fig. 1.

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