COMPUTERS—MACHINES THAT "THINK"

RADIO & TELEVISION NEWS

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THE "UNIVAC" ➧
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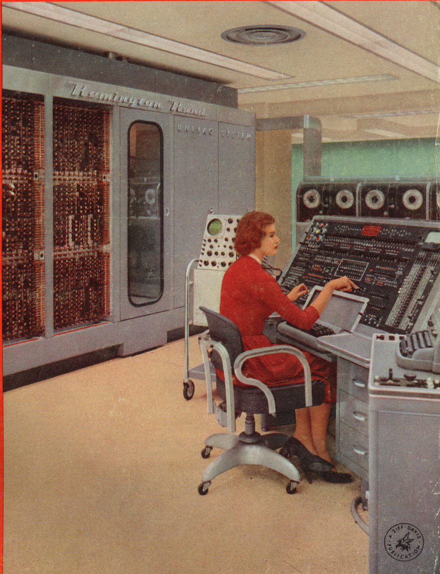

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Behind the Giant Brains

The IBM 650 magnetic drum data processing machine built for commercial use. This machine is designed to meet the accounting and computing needs in areas between those now served by the company's very large and its smaller machines.

By FRANK LEARY

Part 1. Historical development and principles of electronic computers. Here's the story about the devices that are now beginning to shape our lives. To be concluded next month.

ON A RAW afternoon in February, 1946, officials of the Federal government and the University of Pennsylvania, several luminaries of the world of science, and representatives of the press met at the Moore School of Electrical Engineering, on the University of Pennsylvania campus in Philadelphia.

Norbert Wiener, the MIT math professor who was to start a whole cross-section of America using the term *cybernetics,* arrived characteristically without an overcoat. Others parked their wraps and were shown into a large room at the back of the building. Racks of electronic apparatus surrounded them. They were told they were *inside* an electronic calculator which could solve complex differential equations—such as an equation in external ballistics—faster than most people could state the problem. Some were excited, others politely interested, a few were bored. They watched the electronic gadgetry being put through its paces: punched cards with problem data were fed in, cards with answers were punched seconds later. Someone checked the results; they were correct. The press asked some questions, got some answers, and then everybody went to dinner.

These men had been summoned to witness the first public showing of the Moore School's electronic numerical integrator and calculator (a mouthful of description shortened by Army Ordnance officers into the acronym ENIAC). It was not an occasion that seemed particularly world-shaking, but the outgrowths from this machine have been giving the world its share of shudders ever since.

The whole pattern of our existence is being shaped by electronic computers, or "giant brains," to use Edmund C. Berkeley's much abused term. These computers can not only solve complex problems in advanced mathematics, but models now in existence can handle all kinds of information, from a payroll to the Bible. One, the *Remington Rand* "Univac," a lineal descendant of the ENIAC, was recently used by the *Thomas J. Nelson Publishing Company* to compile the Concordance for the Revised Standard Version of the Holy Bible. Other systems are gradually infiltrating our daily lives: our social security accounts, our insurance policy information, our income tax records, all are being converted onto files of magnetic tapes, which can be swiftly and efficiently processed by these automatic electronic computers.

The Monster on the Second Floor

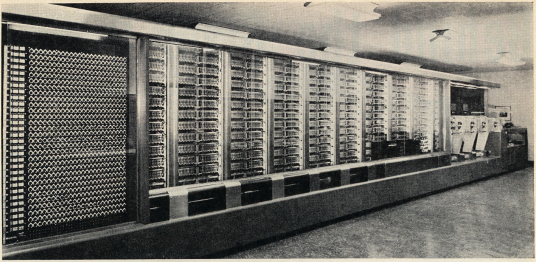
The reactions of people associated with them are as varied as opinions about the proper proportions for a martini. Some people—notably the designers—feel that these computers are the greatest boon to mankind since the invention of the round wheel. Others, seeing phantoms of technological displacement, redeployment, and unemployment, regard the introduction of electronic brains into everyday affairs with great distaste. More considered opinions place atomic energy and automatic computers on the same level, as the two most important technological advances to have come out of the War.

In the New York office of one of the major manufacturers of the giant electronic computers, a system has been set up to operate as a computing service bureau on the second floor of the building. One of the old-line employees of this corporation refers consistently to the machine as "the monster on the second floor." No amount of persuasion, exhortation, or scientific evidence can convince him that it is anything but a monster.

War Babies

ENIAC, the first of all these electronic "monsters"—no more monster than the thermostat that turns your heat on and off—has been working around the clock at Aberdeen Proving Grounds ever since it was moved there in 1948. Another of the computer industry's grandparents sits where it was first built, at Harvard. This is the famous Aiken Relay Calculator Mark I, first of all truly automatic computers, built in 1944 by Harvard Computation Laboratories for the U. S. Navy. The two of them, different in concept but complementary to each other, have sired many progeny.

Mark I was not electronic; ENIAC was. Mark I was automatically sequenced, which is to say, it was capable of automatically performing a series of instructions fed to it from punched paper tape; ENIAC recognized patterns of instructions set up in advance on wiring panels. Modern computers, which are generally both electronic *and* automatically sequenced, are logically descended from both "old" designs.



All computing and processing of information in the Harvard Mark I was performed by means of high-speed relays. This is what the calculator looks like today, after some modifications have been made.

Mark I and ENIAC were both "war babies." Army Ordnance, trying to supply complete ballistic data on new weapons to Army field commanders, had pricked up its ears when John W. Mauchly, then an assistant professor on the staff of the Moore School, and now an executive of *Remington Rand's* "Univac" division, had suggested an electronic calculator as a possible solution; Ordnance funds sponsored the construction of ENIAC. Mark I, designed by Harvard's Howard Aiken and built by his staff in cooperation with *International Business Machines Corporation*, was fostered by the similar needs of Navy Ordnance.

From these original wartime projects have sprung the burgeoning family of electronic digital computers—computers which recognize and electronically process actual numbers, or alphabetic characters, and not varying voltage levels, or turns of a cogwheel or gear or axle. The latter, called analogue computers, form a completely different family, with a somewhat similar heritage, but with different parents, and different uses.

The Tributary Currents

Several separate streams have joined to form the torrent of activity that the computer industry has become.

The principal headwater is an old and familiar one: man has always sought ways of harnessing nature to serve him. Mathematicians are no exception, and creative mathematicians especially have frequently bridled at the plain stickwork involved in the rigorous proofs of their theories. Pascal, Leibnitz, Gauss, and Maxwell are among the great scientists who designed and built mechanical aids to calculation. These machines were of some help to their creators, but of little general use.

Another stream first was struck by a watchmaker named Jacques de Vaucanson, who, in 1741, invented a delicate automatic loom for weaving figured silks. The designs in the silks were established by patterns of holes punched in a metal drum; the holes controlled the raising and lowering of the treadles. In 1804, Joseph Marie Jacquard adapted the idea to a much larger scale for weaving tapestries, rugs, and other heavier materials. To increase the utility of his automatic loom, Jacquard used as controls punched sheets of stiff paper which could be changed fairly easily. Within eight years, eleven thousand Jacquard looms had been placed in operation in France.

The name of Charles Babbage, one of the two men in history ever to hold the Lucasian professorship of mathematics at Oxford University, is a revered one in the computer field, for Babbage was the first to envisage a truly general-purpose computer. He also merged the de Vaucanson-Jacquard idea, of storing information as punched holes in a sheet of paper, with the idea of mechanical computation.

Babbage began work on what he called a *difference engine* in 1823. The purpose of the engine was to provide mechanical assistance for advanced mathematical computations. The British government offered some financial support to his project, and he was able to draw up working diagrams and specifications. But this was the era of Watt's steam engine, when the criterion for the fit of a piston within the cylinder wall was that a thin sixpence could just be slipped between the two; built to such tolerances, Babbage's difference engine, and his later *analytical engine*, could never be made to produce reliable answers. Eventually the government withdrew support, and the Babbage designs became historical curiosities. Many of today's mechanical and electronic calculators, however, possess a logical organization remarkably similar to the analytical engine which was the triumph and despair of Babbage's life.

Enter the Census Bureau

Mechanical tabulators, capable of simultaneously registering horizontal and vertical sums, were the next important development. These grew, quite naturally, out of the needs for statistical analysis, and many of the most important advances were made in the U. S. Bureau of the Census. For example, Charles Seaton, who was Chief Clerk of the Census Bureau, invented such a mechanical tabulator in 1872. And in 1887, Dr. Herman Hollerith, then chief of Census' tabulation section, further adapted the Jacquard punched-paper control system to the accumulation of statistical data. This was a most important stride in mechanical computation, for it introduced into a working system the concept of mechanically stored (remembered) information, which could be used for many calculations or tabulations without the necessity for re-entering the data from a keyboard. The Hollerith equipment was one of the ancestors of familiar punched-card equipment.

During the eleventh decennial census (1890), another member of the Census Bureau staff, James Powers, developed another kind of mechanical tabulator which also used punched cards. The Hollerith holes were rectangular; the Powers holes were round. Both types of equipment were used by Census for years—are still in use, in fact. Both men left the Census Bureau to merchandise their ideas in the commercial world. Descended from the Powers' idea are the familiar *Remington Rand* and *Underwood-Samas* round-hole cards, while Hollerith's idea is found in the equipment of *International Business Machines, Compagnie des Machines Bull,* and others.

Just prior to Hollerith's and Powers' inventions, a host of mechanical "arithmetic engines," which we would today call adding machines, were patented. One of the most important of these was the 1885 adding machine of William Seward Burroughs, probably the first to be designed for production in quantity. These machines were the ancestors of the modern desk calculator, now emerging, complete with high-speed electronic and magnetic components, as a serious contender for the attention of the computing public.

For years following the invention of the various kinds of punched-card tabulators and calculators—until about the time of World War II—these machines were the highest order of mechanical aids to computation. But the third major contributory stream actually had appeared as early as December, 1919, when a paper describing an electronic "trigger circuit" that could be used for counting pulses of electrical energy was published in the first volume of *Radio Review.* The authors of the paper were W. H. Eccles and F. W. Jordan; the Eccles-Jordan trigger circuit, and its many modifications—multivibrators, one-shot trigger pairs, and so forth—all of which are familiar to the world of television and radar, are foundation blocks of the electronic digital computer as we know it.

While punched-card calculators were growing larger and more complex, a small group of scientific minds saw the coming of an era when mechanical devices, however fast, efficient, and succinct, would not be capable of keeping pace with the need for information. All over the country, the capacity of punched-card calculator centers was exceeded and expanded and exceeded again. In the late thirties, men in widely separated activities began asking "can we apply electronics to this problem?" And more and more frequently, the answer was "yes."

The Analogue Computers

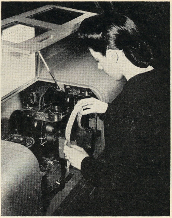
A group of scientists and engineers, sparked by the physicist Vannevar Bush, had meanwhile been pursuing another tack. During the twenties, Bush had merged an idea of Lord Kelvin's, some of Babbage's concepts, and the then-recent development of mechanical torque amplifiers. From this merger, he developed a reliable mechanical device for the rapid and automatic analysis of differential equations. Several of these differential analyzers were built from his plans at various universities in this country and Europe. They were not digital calculators as envisaged by Babbage and as built by the various punched-card manufacturers. They formed a major group within the completely different class of analogue computers.

Analogue computers derive their name from the fact that they compute by mechanical or electrical analogy. The turning of a gear, or a set of gears, through part or all of a revolution may be used to represent, by analogy, a parameter in an equation. Or the movement of a diagonal slide in a rectangular frame may represent another parameter. Various torque converters or torque amplifiers perform operations analogous to mathematical computations.

A simple analogue computer could be made from two circular gears in the ratio of 3.1416 to 1. Turning the larger gear would cause the smaller to be displaced 3.1416 times as much. If angular displacements were shown on a pair of calibrated dials, one could multiply by *pi* (approximately) on this simple device. Numerical values for a diameter could be entered on the larger dial, and instantaneous approximate values for the circumference would be read on the dial for the smaller gear. (Such a device would, of necessity, produce approximations, since *pi* cannot be exactly represented by a ratio of integers.)

Similarly, a large variable resistor might be wound on a card shaped like a sine curve, instead of being wound on the usual rectangular card. The angle of displacement of the wiper arm would then be a parameter in the equation; the voltage applied across the resistor would be multiplied by the *sine* of this angle when tapped by the wiper. Another wiper 90° displaced from the first would simultaneously produce a voltage analogous to the *cosine* of the same angle.

Complexes of such mechanical and electrical analogies could be assembled into computing systems which represented the equations of external ballistics, for example. Such analogue computers were much used during the second World War for artillery fire-control, in conjunction with radar tracking systems. *Bell Laboratories, Sperry, Westinghouse,* and *General Electric,* among others, all built analogue computers for the Army and Navy. More recently, such systems have been used in industry for a.c. network analysis, for the analysis and synthesis of gas distribution systems, and in many instances for the simulation of fairly complex machinery or systems (such as missile systems or ultra-thin high-speed propeller blades) prior to their design and construction. Because they work so readily with physical measuring and instrumentation apparatus, and with mechanical or electronic controls, they are also natural choices for the needs of industrial automation.

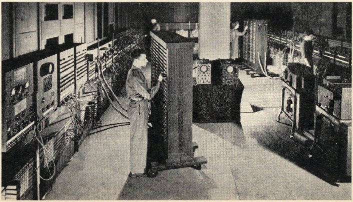


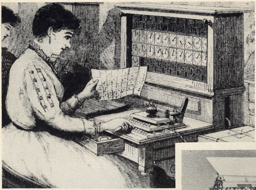
Punched paper tape, such as that which is shown in the photo in use in the famous Bell Relay Calculator, was the source of Harvard Mark I's instructions and programming.

The Differences

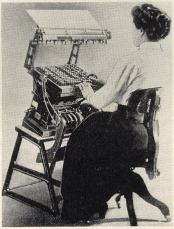
Analogue computers are eminently suited for representing involved equations in physical form. In design work, they permit the varying of parameters by analogy, to determine the effect of such variations on the system as a whole. As control systems for indus-

The ENIAC as it looked when it was installed at the Moore School of the University of Pennsylvania. The hundreds of cables, carrying control and information signals from one part of the computer to another, all had to be set up before a problem was run. Newer computers are somewhat more sophisticated, can vary operations through a stored program of instructions.

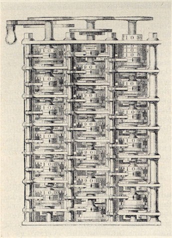




← Herman Hollerith's electric counting machine as used in the 1890 census. The accumulated and tabulated results were presented on the counter dials, and had to be copied off by hand.



The first die-set punch, developed by → Powers for the census of 1910. The operator set up on the keyboard all the values to be punched; she then used the knee-treadle to gang-punch the card.



← The accumulator of Charles Babbage's difference engine, from an old woodcut.

trial automation, they can adjust valves, speed up or slow down transfer systems, and so forth, as required by the standards of the output product desired.

Analogue computers possess two inherent limitations. First, they cannot easily be used for dissimilar problems. The computer itself is a mechanical or electrical analogy to an equation; changing the equation means changing the hardware of the computer. Second, they are generally only precise to two or three significant figures, depending on the fineness of construction; and their accuracy depends, not only on the accuracy of the input data, but also on the instruments which present the answers (calibrated oscilloscopes, meters, counters, etc.), and on the subjective "feel" of the operator who inspects these presentations.

A digital computer can process ordinary numbers or alphabetic characters without any trouble at all. It can handle continuously variable data only by "digitalizing" it—sampling the value of the continuous function at regular time intervals and giving it a numerical representation—and then applying the methods of numerical analysis; but it can generally do far more types of work than an analogue computer, and, once the information is translated into discrete digital form, it never loses a decimal point of precision. Furthermore, the accuracy of the digital computer's work can easily be checked by inverse operations (proving addition by subtraction, etc.), by identical parallel operations compared for identical answers, or by many other means.

General-purpose digital computing systems are far simpler than analogue networks (although some of them are much larger); they can basically only add, compare, and discriminate between relative magnitudes, store (or remember, if you prefer) information, and shift the information around. Mostly they subtract by inverse addition, multiply by repeated addition, and divide by alternately performing repeated additions and subtractions. Depending on their discriminatory abilities, they can select paths of action, or sort information, or start (or stop) a process. They can, in other words, be empowered to make decisions.

Note well: *be empowered* to make decisions. The two most mystifying things, to many people outside the field, are that these machines seem to make decisions, and seem to remember information. Neither one is at all mysterious.

How Machines Remember

Memory, for example, as a machine function, is quite familiar to everyone. A thermostat remembers two things: you tell it how hot you want it to be by setting the value on a dial (which at the same time sets a control contact), and a bimetallic thermometer tells it how hot it actually is. When the thermometer tells it that the temperature has fallen below your setting, it turns on the heat.

A wall switch remembers that you turned it on, but the little button on a flashlight, which must be locked to remain on, does not; as soon as you release it, it "forgets" it was on and goes out. An annoying characteristic of certain cathode-ray tube phosphors, for television purposes, is persistence; this is nothing more than the phosphor's "remembering" the current which excited it into phosphorescence, and continuing to glow after the current is gone. The characteristic was used to advantage in a type of computer memory.

A magnetic tape or wire, or an acetate or vinyl disc, remembers the information put on it for a long time. Materials which are truly elastic cannot remember; they snap back into their normal state too readily. Brittle materials (such as glass after its elasticity has been exceeded) are crude memories only, because they cannot be restored. The most concentrated effort in developing memory systems has been expended on hysteretic materials—materials which exhibit a time-lag between the removal of a stimulus and the restoration of the material to its normal state. Magnetic materials are an ideal example; after the magnetizing current is removed, a certain amount of magnetism remains in the material (for a period of time depending on the material). And much of the most fruitful effort in designing and building computer memories has been devoted to magnetics research.

How Machines Make Decisions

The way the thermostat "decides" to turn on the heat is an excellent illustration of the type of decision-making common in the computing machine. When the actual temperature sensed by the thermometer falls below the setting of the contact, the heat comes on. Now the thermostat setting is an artificially established control point, set by a human operator; the control contact is moved closer to or farther from the contact on the bimetallic thermometer as the operator decides the temperature should be higher or lower. The ability to reach a decision to turn heat on or off is built into the thermostat, in that electrical power connects through the two contacts to start a blower motor or automatic stoker.

A computer, which can compare

quantities and discriminate between them, can choose one of several paths of action in terms of the relative magnitudes of the two quantities. The ability to select the alternate routes is built into the computer; the criteria for the selection are given to it by the controlling human agency. The giant brain and the simple thermostat both have the same degree of mindless unawareness of what they are doing.

In making its decisions, the computer merely transfers control when one quantity equals another, exceeds another, becomes less than another, or goes through zero. If control is transferred to an instruction which tells it to "add," it adds; "stop," it stops; "rewind tape," it rewinds tape, and so forth.

A set of values can be given to the computer, and its comparison circuits can check each one of the set, making several "yes-no" choices which lead to a compound conclusion. In making these choices, the computer actually seems to be exhibiting a complex type of judgment, but each single decision remains a "yes" or "no" choice. The computer's secret is that it handles the most complicated problem in the world in the simplest and most primitive steps. It is exactly like an expert player of "Twenty Questions," who can narrow down on a single object out of all the objects in the world by getting twenty "yes-or-no" answers.

It is an error to romanticize, humanize, or personify these devices. They are completely unimaginative servants; they can do exactly what they are told, provided a tube doesn't burn out, and provided also that what they are told is consistent with what they can do; but they can do no more. They are controlled by the men who make them, the men who operate them, and the men who program them. They are especially at the mercy of the men who turn them off when the day is through.

Any time a computer seems to show imagination, it is because someone used imagination in designing its program. If a "giant brain" solves a problem, it is because someone (*a*) knew exactly how to go about solving that problem, and (*b*) knew precisely how to instruct the equipment in the procedures for solving that problem. If anyone ever gets one of these computers to write a symphony, for example, it will be because that person knows the laws of melody and harmony, counterpoint, orchestral placement, musical structure, and scoring, and knows what limits to set, and knows further how to translate all these laws, maxims, and principles into an abecedarian lingo that the simpleminded "brain" can follow. Anyone who can do that could write the symphony himself, in less time than it would take to get the computer to do it. The only advantage would be that the computer could turn out an infinitude of remarkably similar symphonies at an extremely rapid rate.

(Concluded next month)

COVER STORY

The "Univac"

An Electronic Brain for Industry

BUSINESS and industry, hard-pressed for information to aid management, turn to computers for help—and find it!

The giant electronic computers no longer rank as laboratory curiosities or frightening science-fiction robots. Imaginative businessmen, hard-pressed by a shortage of clerical help, have put them quietly to work in the accounting office, the stockroom, and wherever else work can be routinized.

First of the giant brains to be built specifically for business, the Remington Rand "Univac" has been familiar to most Americans through the role it has played in predicting the outcome of the last three national elections. On last November's election evening, with less than 1/2 per-cent of the votes (300,000) counted, the "Univac" predicted at 7:15 p.m., EST, that the odds were 100 to 1 in favor of an Eisenhower landslide and that only 87 electoral votes were likely to wind up in the column of candidate Stevenson. By midnight, "Univac" had virtually pinpointed the final results with a forecast that President Eisenhower's plurality would be 9,269,524, totalling 58 per-cent of the popular vote to Stevenson's 42 per-cent. (The actual plurality, as of the time of this writing, is very close to 9,312,700).

The first political forecast of "Univac" was made back in 1952. Then, with 3,380,000 votes reported, "Univac" also quoted odds of 100 to 1, predicting 438 electoral votes for Eisenhower and 93 for Stevenson (final returns: 442 to 89). At that time, only six "Univac" systems had been sold; these six were all the general-purpose business data-processing systems that had ever been built. Now about a dozen large office-equipment and electronics manufacturers are engaged in the building of big computers; half a hundred more companies are building major systems components. What was a minor novelty in 1951 has become a several-hundred-million-dollar industry in the remarkably brief ensuing period of a little over five years' time.

The "Univac" system shown on the cover of this month's issue is one of the two such systems installed by the Consolidated Edison Company of New York to process its customers' accounts. Over a hundred large-scale computing systems of this type are already working for American business and industry across the land, in various government agencies, and in a great many military establishments and equipment, as are described in the article "Behind the Giant Brains," in this issue.

The distinguishing feature of the "Univac," when it was introduced in 1951, was not its computing speed; its own predecessor, the "Binac," could compute almost two times as fast, and many other machines released before or since were faster than the Remington Rand development. "Univac's" forte was in flexibility; it was one of the first big computers to be able to handle numbers and alphabetic characters with equal ease; it was the very first computing system to use high-speed magnetic tape recording to get information into the computer and get results out. High-speed tape input and output, of course, permits the rapid handling and processing of information in volume. Since most problems of business and industry are characterized by masses of alphabetic or numerical information on which a relatively small amount of computing or processing is done, input-output facilities make the difference between a scientific computer and a data processor which is truly applicable to large-scale business problems.

"Univac" is also unusual in being a self-checking computer. Over a third of the circuitry in the large central computer cabinet is devoted to checking and verifying operations. Every arithmetical process, all transfers of information, and even the instruction set-ups, control functions, and so forth, are checked. Inconsistencies, discrepancies, etc., cause the computer to stop and alert the operator to their presence and location. Since the machine cannot introduce an undetected error, processed results are thoroughly reliable.

It is difficult to estimate the savings which have accrued to dozens of computer users, because these savings are both direct and indirect. Not only do companies relieve pressure on their overburdened clerical staffs, and eliminate the many machines which formerly did the work now done by computers; but they also do work which they had never planned, hoped, or intended to do before; work which only a high-speed electronic computer can make possible. And in this realm, of course, there is no basis for comparison. But in every case, companies which have leased or purchased such computers made their decisions to do so after their own staffs had made exhaustive surveys which pointed conclusively to substantial and measurable savings over other systems. In this field, as in almost any other, the searching criterion of economy has brought us into the electronic age.

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