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The Thinking Machine

(See Cover)

On Oxford Street in Cambridge, Mass. lives a sibyl, a priestess of science. Her devotees take their problems to her as devout ancient Greeks took their insolubles to Delphi. She is no mumbling, anonymous priestess, frothing her mouth with riddles. Her name is Bessie*; she is a long, slim, glass-sided machine with 760,000 parts, and the riddles that are put to her and that she unfailingly answers concern such matters as rocket motors, nuclear physics and trigonometric functions.

For a computing machine, Bessie is old: she has been steadily at work since 1944. And she is not the brightest of her breed. Compared to her children and grandchildren (one of whom, Harvard's Mark III —see cover—lives on the floor below in Harvard's Computation Laboratory), she is dim-witted and slow. But Bessie is a progenetrix, a sort of mechanical Eve. By proving what computing machines could do, she started one of the liveliest developments in modern science.

Some scientists think that Bessie's descendants will have more effect on mankind than atomic energy. Modern man has become accustomed to machines with superhuman muscles, but machines with superhuman brains are still a little frightening. The men who design them try to deny that they are creating their own intellectual competitors.

Seed of the Abacus. The calculating machines that are Bessie's ancestors have roots far back in the past. The abacus, used in ancient Egypt and still used in much of Asia, is a simple figuring device. The French mathematician Blaise Pascal (1623-62) designed a mechanical calculator when Louis XIII was king. The present adding machine is a remote descendant of Pascal's design.

But an adding machine, compared to one of Bessie's breed, is a dumb, limited brute. It accepts numbers through its keyboard and "remembers" them by the setting of its mechanism. When the operator gives a command by pressing another key, the machine adds or subtracts the numbers in its "memory." Then it stops, waiting for another command.

Bessie and her children do not stop and wait. They accept not only a flood of numbers but also elaborate instructions (often in the form of holes in a paper tape). When all the facts are in, the operator presses a starting button—and the machine quickly does the rest.

It may, for example, multiply a 16-digit number by another number just as long, subtract something from the product, square the result and add something to the square. From time to time it refers to tables of figures imbedded in its memory, selects the proper figure and includes it in its calculations. It remembers intermediate figures for a fraction of a second, uses them when needed, and then rubs them out like chalk marks on a blackboard. It does all these things and more, without mistakes, faster than a human being can jot down a single figure. When the machine is through with one calculation, it rattles out the answer on an electric typewriter and starts the next job in a flash.

What practical jobs can a calculator do? Merely describing its complex problems would require difficult mathematics, but there are some simple examples.

Bessie in Flight. During World War II, old Bessie (built by International Business Machines Corp. and presented by I.B.M. to Harvard) was given the job of evaluating mathematically an electrically powered cannon that the Nazis were known to be building. Bessie chewed into a snarl of equations and proved that the weapon was utterly impractical. The U.S. relaxed while the Germans, who had no Bessie, went on wasting enormous effort on an impossible task.

When not more urgently engaged, Bessie grinds out whole books of useful mathematical tables. One of them has 290 pages solidly packed with figures. A skilled operator, working with a desk calculator (an elaborate "adding machine"), might have completed the task in several years of steady, grueling labor. Bessie took twelve days to do the job.

One of Bessie's recent chores was finding out how to get the greatest range out of an Air Force bomber. She was given a complicated equation expressing the airplane's flying characteristics. By substituting different "variables," she figured how far it would fly with various loads, at various altitudes, various engine speeds, etc. When Bessie got through, she started over again, to figure how the plane would perform with one engine dead, two engines dead, etc.

During these theoretical "flights," the young mathematicians in charge of Bessie began to think of her as a real airplane being tested. They groaned when she was ."forced down" and praised her warmly for each extra-tough "flight."

Job of a Century. Such comparatively simple tasks are not impossible for human calculators, but they are impractical because of the time they would take.

But many complicated jobs that the machines can do are beyond human capabilities. The International Business Machines Corp.'s big calculator, for instance, has completed in 103 hours a job (see cut) relating to uranium fission for Princeton University. The same job would have taken a flesh & blood operator more than 100 years. The time could not have been shortened by putting 100 operators to work, because each part of the problem had to be done in sequence.

Feats like this, hitherto impossible for slow, short-lived man, are what make scientists wildly excited about the new computers. Virtually every branch of science is surrounded by beetling walls of unscalable figures. The hazy paths of electrons whirling around a nucleus, the speeding flow of air over an airplane's wing, the structure and reactions of complex chemical molecules—all these involve continents and oceans of figures, figures, figures. Sometimes a simple answer (a small number, or even a yes or a no) would cost a lifetime or 100 lifetimes of human calculation.

Electronic Cobwebs. Laymen are usually baffled When they first look at the machines. Except for Bessie, who has thousands of moving parts that spin and clack entertainingly, they are mostly electronic, and look like the insides of big, enormously complicated radio sets. Among their thousands of vacuum tubes runs a tangled web of fine, insulated wire. On their panels lights flash mysteriously: red lights and white lights dancing like motes in the sunlight as the numbers flow. Harvard's newest machine, Mark III, is probably the handsomest. It was built for the Navy's Bureau of Ordnance, and it looks as spruce and shipshape as a naval officer. At work, it roars louder than an admiral.

Around the machines drifts a dense fog of mathematics, a sort of intellectual tear gas to discomfort the nonmathematical. The machines speak and understand a special language of numbers. These are not "decimal," as ordinary numbers are, built on a base of ten with digits running from 0 to 9. They are "binary" numbers with a base of two, and have only two digits: 0 and 1. In this style of arithmetic, 0 is 0; 1 is i. But 2 is written as 10; 3 is 11; 4 is 100; 5 is 101; 14 is 1110, etc.

Yes-or-No Language. The machines prefer such numbers because their essential parts (electrical relays or vacuum tubes acting like swift relays) obey only two commands: yes or no—i.e., an electrical signal or no signal. So all information fed into the machines has to be predigested into yes-or-no binary arithmetic. Any number, however large, can be expressed in this form. So can elaborate equations like those from the fission problem done for Princeton by the I.B.M. machine. Even languages can be translated in binary numbers. (One way: making different numbers stand for each character, syllable or word.) Any sort of information, once the mathematicians go to work on it, can be broken down into yes-or-no.

But the predigesting job takes some doing. Around each working computer hover young mathematicians with dreamy eyes. On desks flecked with frothy figures, they translate real-life problems into figure-language. It usually takes them much longer to prepare a problem than it takes the machine to solve it.

These human question-askers are sure to lag farther & farther behind the question-answering machines. Mark II, the first calculator built at Harvard for the Navy, is ten times as fast as Bessie. Mark III is 25 times as fast as Mark II and 250 times as fast as Bessie. Machines now abuilding will be faster still. Says Professor Aiken, head of Harvard's Computation Laboratory: "We'll have to think up bigger problems if we want to keep them busy."

Cybernetics Shock. Professor Aiken need not worry: bigger problems are on the way. The success of the automatic calculators set off an explosion of high, wide & handsome pondering that is still reverberating. One of the first recorded tremors was a small, extraordinary book called Cybernetics (John Wiley & Sons; $3), by Professor Norbert Wiener of M.I.T. (TIME, Dec. 27, 1948).

Professor Wiener is a stormy petrel (he looks more like a stormy puffin) of mathematics and adjacent territory. A rarity among scientists, he is willing & able to talk intelligently on almost any subject. Wiener got interested in computing machines while doing war work on gun-pointing mechanisms. His wide-ranging interests (too widely ranging, some of his detractors think) saw in them qualities and possibilities that more practical men had missed.

The great new computers, cried Wiener with mingled alarm and triumph, are not mere mathematical tools. They are, he said, harbingers of a whole new science of communication and control, which he promptly named "cybernetics."* The newest machines, Wiener pointed out, already have an extraordinary resemblance to the human brain, both in structure and function. So far, they have no senses or "effectors" (arms and legs), but why shouldn't they have? There are all sorts of artificial eyes, ears and fingertips (thermometers, strain gauges, pressure indicators, photo-electric tubes) that may be hooked up to the machines. The machines can already work typewriters. They can be built to work valves, switches and all of the other control devices common in modern industry.

Second Revolution. Such a development, says Wiener, is certain. When it does come, he argues, it will usher in "the second industrial revolution," which will devalue the human brain as the first industrial revolution devalued the human arm. He points out that only a few hand workers can now compete with power-driven machines. Soon, he warns, there will be wholly automatic factories with artificial brains keeping track of every process. They will order raw materials, inspect them, store them, route them through the plant. They will pay bills, blow the factory whistle and pay the help (if any).

Many of his colleagues, while admitting that he is a great mathematician, accuse him of sensationalism. Wiener's admirers reply that such bickering is only to be expected in a field as lively as cybernetics. Peace does not reign in a science, they say, until its peaks and valleys have worn to a featureless peneplain grazed by placid ruminants.

What Is Thinking? Do computers think? Some experts say yes, some say no. Both sides are vehement; but all agree that the answer to the question depends on what you mean by thinking.

The human brain, some computermen explain, thinks by judging present information in the light of past experience. That is roughly what the machines do. They consider figures fed into them (just as information is fed to the human brain by the senses), and measure the figures against information that is "remembered." The machine-radicals ask: "Isn't this thinking?"

Their opponents retort that computers are mere tools that do only what they are told. Professor Aiken, a leader of the conservatives, admits that the machines show, in rudimentary form at least, all the attributes of human thinking except one: imagination. Aiken cannot define imagination, but he is sure that it exists and that no machine, however clever, is likely to have any.

What Is the Brain? Wiener believes that the human brain resembles a computing machine—and vice versa. Dr. Warren McCulloch, professor of psychiatry at the University of Illinois College of Medicine, goes further: he says that the brain is actually a computer, and very like computers built by men.

The brain's essential parts, says McCulloch, are "neurons" (nerve cells). There are about 10 billion of them, and they are living electrical relays, comparable to the relays and vacuum tubes in the machines. The neurons are intricately connected by fine, often branching fibers, so the whole brain is a lacelike network of relays and conductors.

Along the brain's interlaced "wires" run swift electrical pulses generated by the neurons, which serve as living batteries. When a pulse runs out along a fiber, it comes eventually to a complicated little structure called a "synapse" that connects with a fiber of another nerve cell. The pulse may pass through a synapse or it may not pass; no one knows why.

When a pulse or several of them do pass, the second neuron "fires," sending out a pulse of its own. Out of such single pulses—billions of them flashing in zigzags and rivers through the thinking brain—human thoughts and decisions are built.

$300 an Hour. Practical computermen, some of whom deplore McCulloch's analogies, agree with him on one point: that the machines need better memories. The machines are already quicker than the brain: their vacuum tubes act 1 ,000 times faster than neurons. But their poor memories (rudimentary compared to the brain's) limit their thinking abilities. The punched tapes and cards that some of them spew out are not real internal memories, since they cannot be consulted quickly. They are more like reference libraries.

Harvard's Mark III, soon to be delivered to the Navy, has the best memory of any machine so far. Its memory is housed in fast-spinning aluminum cylinders whose surfaces are coated with black magnetic material (see cut). On the black surfaces, its electrical signals print long numbers in the form of magnetized dots. When the cylinder makes its next turn, the dots can be read off again in a small fraction of a second. They can be destroyed, replaced with other numbers or retained permanently.

Its quick "magnetic memory" is what makes Mark III an effective computer. Professor Aiken is so well pleased with it that Mark IV, which Harvard is building for the Air Force, will use the same system. Mark IV will "live" (Aiken, the conservative, says "live") at Harvard permanently, and part of its time will be available to non-military users. Scientists will cheer this news. Nearly all the existing computers do nothing but military work. Only the big I.B.M. machine on Manhattan's Madison Avenue is open to nongovernment scientists, and I.B.M. charges $300 an hour for its services.

New, radical memory devices are coming along fast. Among the more promising are "memory tubes." One type, developed by Professor F. C. Williams of Manchester, England, uses a thin beam of electrons to print meaningful dot-numbers on its flat end. They can be used in the machine's calculations and erased electrically in a few millionths of a second.

Memory & Weather. A group led by Julian Bigelow of Princeton's Institute for Advanced Study (whose world-famous mathematician, Professor John von Neumann, developed much of the theory behind modern computers) is building these memory tubes into a machine whose working surfaces are folded upon themselves like the brain's cortex. The machine is intended for such ambitious jobs as long-range weather forecasting.

The factors that cause U.S. weather—varying barometric pressure, temperature, humidity, wind velocity, topography, etc. —interact so intricately that the human brain cannot handle the "burden of computation." During World War II, 40 skilled operators with 40 desk computers tried to keep up with U.S. weather. They fell behind like earthworms paced by a meteor.

Chemicals & Economics. Other practical computing assignments will come from chemistry. The properties of chemical compounds are determined by the characteristics of the atoms that form their molecules; but when chemists try to predict the characteristics of a new compound, not yet synthesized, they run into barriers of figuring. Computers of the future will leap lightly over such barriers. Computermen believe that future chemists will tell the machines to examine thousands of possible compounds in search of the best one: say, a plastic with great elasticity. When such a compound is found, the chemists will set about synthesizing it.

In many other fields the machines will have figuring to do. According to Harvard's Professor Aiken, U.S. economic health depends upon the interaction of 38 industries. But they interact in such complex ways that economists can only guess at present whether they will hatch, a few months later, a boom or a depression. It should be possible for the machines, thinks Aiken, to solve at short intervals a sort of "flow equation" of U.S. economic affairs. After digesting reports on production, payrolls, bank loans, etc., the brainy monsters should be able to forecast economic rain or sunshine. It might even be possible, according to Aiken, to "program" a machine so that it could beat the stock market.

Mechanical Stenographer. Computermen point out that the human brain and the machines speak basically the same language: the simplified language of binary arithmetic. When a stenographer, for instance, listens to her boss's dictation, her ears catch sound waves ("In reply to yours of the 4th . . ."), and turn them into the yes-or-no signals that her neurons demand. Then her neurons send instructions to her finger muscles that result in shorthand scratchings.

There is no reason, say the computermen, why a machine cannot do the same thing. It would need an attachment to turn spoken words into trains of binary numbers. Then the numbers would be turned into typed words. They would not necessarily be spelled phonetically. The machine could decide by reference to memory, just as a flesh & blood stenographer does, how each group of sounds ought to be spelled. Other "memories" would tell it how to clean up the boss's grammar.

Chess Player. Dr. Claude E. Shannon of Bell Telephone Laboratories is figuring how to make a calculator that can play chess. He thinks that one could play well enough to beat all except the greatest chess masters. Machines are also capable, he thinks, of orchestrating a melody and of making simple logical deductions.

Computing machines are very expensive at present; Mark III cost $500,000. But they are becoming simpler, as well as more intelligent, and their cost can be cut enormously by commercial production methods. It is almost certain that they will come into wide use eventually. On Professor Aiken's desk are sheaves of letters from corporations eager to learn about the computers' potentialities.

Nearly all the computermen are worried about the effect the machines will have on society. But most of them are not so pessimistic as Wiener. Professor Aiken thinks that computers will take over intellectual drudgery as power-driven tools took over spading and reaping. Already the telephone people are installing machines of the computer type that watch the operations of dial exchanges and tot up the bills of subscribers.

Psychotic Robots. In the larger, "biological" sense, there is room for nervous speculation. Some philosophical worriers suggest that the computers, growing superhumanly intelligent in more & more ways, will develop wills, desires and unpleasant foibles' of their own, as did the famous robots in Capek's R.U.R.

Professor Wiener says that some computers are already "human" enough to suffer from typical psychiatric troubles. Unruly memories, he says, sometimes spread through a machine as fears and fixations spread through a psychotic human brain. Such psychoses may be cured, says Wiener, by rest (shutting down the machine), by electric shock treatment (increasing the voltage in the tubes), or by lobotomy (disconnecting part of the machine).

Some practical computermen scoff at such picturesque talk, but others recall odd behavior in their own machines. Robert Seeber of I.B.M. says that his big computer has a very human foible: it hates to wake up in the morning. The operators turn it on, the tubes light up and reach a proper temperature, but the machine is not really awake. A problem sent through its sleepy wits does not get far. Red lights flash, indicating that the machine has made an error. The patient operators try the problem again. This time the machine thinks a little more clearly. At last, after several tries, it is fully awake and willing to think straight.

Neurotic Exchange. Bell Laboratories' Dr. Shannon has a similar story. During World War II, he says, one of the Manhattan dial exchanges (very similar to computers) was overloaded with work. It began to behave queerly, acting with an irrationality that disturbed the company. Flocks of engineers, sent to treat the patient, could find nothing organically wrong. After the war was over, the work load decreased. The ailing exchange recovered and is now entirely normal. Its trouble had been "functional": like other hard-driven war workers, it had suffered a nervous breakdown.

Future machines may be above such weaknesses and able to take over more & more kinds of thinking. According to Mc-Culloch, human brains have been decreasing in size since the time (20,000 years ago) of Cro-Magnon Man. McCulloch suggests sardonically that this may be nature's reaction to the fact that as man's society becomes more elaborate, individual men find less need for their brains.

Ruler or Tool? Perhaps the computing machines, by lifting more of the thinking burden, will prove a last step in the long, slow process of mental collectivization. Men may come to specialize on the simple, narrow tasks of serving the machines. Men's brains may grow smaller & smaller as the machines' brains grow larger. Will the time come at last when the machines rule—perhaps without seeming to rule—as the mysterious "spirit of the colony" rules individual ants?

To all such chilling speculation, the young engineers in Professor Aiken's laboratory have a breezy answer: "When a machine is acting badly, we consider it a responsible person and blame it for its stupidity. When it's doing fine, we say it is a tool that we clever humans built."

*Short for "Bessel Functions," a mathematical tool analogous to logarithms. *From the Greek word meaning steersman.