CAN MACHINES THINK?
WHAT IS A MECHANICAL BRAIN?

Recently there has been a good deal of news about strange giant machines that can handle information with vast speed and skill. They calculate and they reason. Some of them are cleverer than others—able to do more kinds of problems. Some are extremely fast: one of them does 5000 additions a second for hours or days, as may be needed. Where they apply, they find answers to problems much faster and more accurately than human beings can; and so they can solve problems that a man’s life is far too short to permit him to do. That is why they were built.

These machines are similar to what a brain would be if it were made of hardware and wire instead of flesh and nerves. It is therefore natural to call these machines mechanical brains. Also, since their powers are like those of a giant, we may call them giant brains.

Several giant mechanical brains are now at work finding out answers never before known. Two are in Cambridge, Mass.; one is at Massachusetts Institute of Technology, and one at Harvard University. Two are in Aberdeen, Md., at the Army’s Ballistic Research Laboratories. These four machines were finished in the period 1942 to 1946 and are described in later chapters of this book. More giant brains are being constructed.

Can we say that these machines really think? What do we mean by thinking, and how does the human brain think?
HUMAN THINKING

We do not know very much about the physical process of thinking in the human brain. If you ask a scientist how flesh and blood in a human brain can think, he will talk to you a little about nerves and about electrical and chemical changes, but he will not be able to tell you very much about how we add 2 and 3 and make 5. What men know about the way in which a human brain thinks can be put down in a few pages, and what men do not know would fill many libraries.

Injuries to brains have shown some things of importance; for example, they have shown that certain parts of the brain have certain duties. There is a part of the brain, for instance, where sights are recorded and compared. If an accident damages the part of the brain where certain information is stored, the human being has to relearn—haltingly and badly—the information destroyed.

We know also that thinking in the human brain is done essentially by a process of storing information and then referring to it, by a process of learning and remembering. We know that there are no little wheels in the brain so that a wheel standing at 2 can be turned 3 more steps and the result of 5 read. Instead, you and I store the information that 2 and 3 are 5, and store it in such a way that we can give the answer when questioned. But we do not know the register in our brain where this particular piece of information is stored. Nor do we know how, when we are questioned, we are able automatically to pick up the nerve channels that lead into this register, get the answer, and report it.

Since there are many nerves in the brain, about 10 billion of them, in fact, we are certain that the network of connecting nerves is a main part of the puzzle. We are therefore much interested in nerves and their properties.

NERVES AND THEIR PROPERTIES

A single nerve, or nerve cell, consists of a cell nucleus and a fiber. This fiber may have a length of anything from a small fraction of an inch up to several feet. In the laboratory, successive impulses can be sent along a nerve fiber as often as 1000 a second. Impulses can travel along a nerve fiber in either direction at a rate from 3 feet to 300 feet a second. Because the speed of the impulse is far less than 180,000 miles a second—the speed of an electric current—the impulse in the nerve is thought by some investigators to be more chemical than electrical.

We know that a nerve cell has what is called an all-or-none response, like the trigger of a gun. If you stimulate the nerve up to a certain point, nothing will happen; if you reach that point, or cross it,—bang!—the nerve responds and sends out an impulse. The strength of the impulse, like the shot of the gun, has no relation whatever to the amount of the stimulation.

The structure between the end of one nerve and the beginning of the next is called a synapse (see Fig. 1). No one really knows very much about synapses, for they are extremely small and it is not easy to tell where a synapse stops and other stuff begins. Impulses travel through synapses in from $\frac{1}{2}$ to 3 thousandths of a second. An impulse travels through a synapse only in one direction, from the head (or axon) of one nerve fiber to the foot (or dendrite) of another. It seems clear that the activity in a synapse is chemical. When the head of a nerve fiber brings in an impulse to a synapse, apparently a chemical called acetylcholine is released and may affect the foot of another fiber, thus transmitting the impulse; but the process and the conditions for it are still not well understood.

It is thought that nearly all information is handled in the brain by groups of nerves in parallel paths. For example, the eye is estimated to have about 100 million nerves sensitive to
light, and the information that they gather is reported by about 1 million nerves to the part of the brain that stores sights.

Not much more is yet known, however, about the operation of handling information in a human brain. We do not yet know how the nerves are connected so that we can do what we do. Probably the greatest obstacle to knowledge is that so far we cannot observe the detailed structure of a living human brain while it performs, without hurting or killing it.

**BEHAVIOR THAT IS THINKING**

Therefore, we cannot yet tell what thinking is by observing precisely how a human brain does it. Instead, we have to define thinking by describing the kind of behavior that we call thinking. Let us consider some examples.

When you and I add 12 and 8 and make 20, we are thinking. We use our minds and our understanding to count 8 places forward from 12, for example, and finish with 20. If we could find a dog or a horse that could add numbers and tell answers, we would certainly say that the animal could think.

With no trouble a machine can do this. An ordinary 10-column adding machine can be given two numbers like 1,378,917,766 and 2,355,799,867 and the instruction to add them. The machine will then give the answer, 3,734,717,633, much faster than a man. In fact, the mechanical brain at Harvard can add a number of 23 digits to another number of 23 digits and get the right answer in 3/16 of a second.

Or, suppose that you are walking along a road and come to a fork. If you stop, read the signpost, and then choose left or right, you are thinking. You know beforehand where you want to go, you compare your destination with what the signpost says, and you decide on your route. This is an operation of logical choice.

A machine can do this. The mechanical brain now at Aberdeen which was built at Bell Laboratories can examine any number that comes up in the process of a calculation and tell whether it is bigger than 3 (or any stated number) or smaller. If the number is bigger than 3, the machine will choose one process; if the number is smaller than 3, the machine will choose another process.

Now suppose that we consider the basic operation of all thinking: in the human brain it is called learning and remembering, and in a machine it called storing information and then referring to it. For example, suppose you want to find 305 Main Street in Kalamazoo. You look up a map of Kalamazoo; the map is information kindly stored by other people for your use. When you study the map, notice the streets and the numbering, and then find where the house should be, you are thinking.

A machine can do this. In the Bell Laboratories’ mechanical brain, for example, the map could be stored as a long list of the blocks of the city and the streets and numbers that apply to each block. The machine will then hunt for the city block that contains 305 Main Street and report it when found.

A machine can handle information; it can calculate, conclude, and choose; it can perform reasonable operations with information. A machine, therefore, can think.

**THE DEFINITION OF A MECHANICAL BRAIN**

Now when we speak of a machine that thinks, or a mechanical brain, what do we mean? Essentially, a mechanical brain is a machine that handles information, transfers information automatically from one part of the machine to another, and has a flexible control over the sequence of its operations. No human being is needed around such a machine to pick up a physical piece of information produced in one part of the machine, personally move it to another part of the machine, and there put it in again. Nor is any human being needed to give the machine instructions from minute to minute. Instead, we can write out the whole program to solve a problem, translate the program into machine language, and put the program into the machine. Then we press the “start” button; the machine starts whirring; and it prints out the answers as it obtains them. Machines that handle information have existed for more than 2000 years. These two properties are new, however, and make a deep break with the past.
How should we imagine a mechanical brain? One way to think of a mechanical brain is shown in Fig. 2. We see here a railroad line with four stations, marked input, storage, computer, and output. These stations are joined by little gates or switches to the main railroad line. We can imagine that numbers and other information move along this railroad line, loaded in freight cars. Input and output are stations where numbers or other information go in and come out, respectively. Storage is a station where there are many platforms and where information can be stored. The computer is a special station somewhat like a factory; when two numbers are loaded on platforms 1 and 2 of this station and an order is loaded on platform 3, then another number is produced on platform 4.

We see also a tower, marked control. This tower runs a telegraph line to each of its little watchmen standing by the gates. The tower tells them when to open and when to shut which gates.

Now we can see that, just as soon as the right gates are shut, freight cars of information can move between stations. Actually the freight cars move at the speed of electric current, thousands of miles a second. So, by closing the right gates each fraction of a second, we can flash numbers and information through the system and perform operations of reasoning. Thus we obtain a mechanical brain.

In general, a mechanical brain is made up of:

1. A quantity of registers where information (numbers and instructions) can be stored.
2. Channels along which information can be sent.
3. Mechanisms that can carry out arithmetical and logical operations.
4. A control, which guides the machine to perform a sequence of operations.
5. Input and output devices, whereby information can go into the machine and come out of it.
6. Motors or electricity, which provide energy.

**THE KINDS OF THINKING A MECHANICAL BRAIN CAN DO**

There are many kinds of thinking that mechanical brains can do. Among other things, they can:

1. Learn what you tell them.
2. Apply the instructions when needed.
3. Read and remember numbers.
4. Add, subtract, multiply, divide, and round off.
5. Look up numbers in tables.
6. Look at a result, and make a choice.
7. Do long chains of these operations one after another.
8. Write out an answer.
9. Make sure the answer is right.
10. Know that one problem is finished, and turn to another.
11. Determine most of their own instructions.

They do these things much better than you or I. They are fast. The mechanical brain built at the Moore School of Electrical Engineering at the University of Pennsylvania does 5000 additions a second. They are reliable. Even with hundreds of thousands of parts, the existing giant brains have worked success-
fully. They have remarkably few mechanical troubles; in fact, for one of the giant brains, a mechanical failure is of the order of once a month. They are powerful. The big machine at Harvard can remember 72 numbers each of 23 digits at one time and can do 3 operations with these numbers every second. The mechanical brains that have been finished are able to solve problems that have baffled men for many, many years, and they think in ways never open to men before. Mechanical brains have removed the limits on complexity of routine: the machine can carry out a complicated routine as easily as a simple one. Already, processes for solving problems are being worked out so that the mechanical brain will itself determine more than 99 per cent of all the routine orders that it is to carry out.

But, you may ask, can they do any kind of thinking? The answer is no. No mechanical brain so far built can:

1. Do intuitive thinking.
2. Make bright guesses, and leap to conclusions.
3. Determine all its own instructions.
4. Perceive complex situations outside itself and interpret them.

A clever wild animal, for example, a fox, can do all these things; a mechanical brain, not yet. There is, however, good reason to believe that most, if not all, of these operations will in the future be performed not only by animals but also by machines. Men have only just begun to construct mechanical brains. All those finished are children; they have all been born since 1940. Soon there will be much more remarkable giant brains.

**WHY ARE THESE GIANT BRAINS IMPORTANT?**

Most of the thinking so far done by these machines is with numbers. They have already solved problems in airplane design, astronomy, physics, mathematics, engineering, and many other sciences, that previously could not be solved. To find the solutions of these problems, mathematicians would have had to work for years and years, using the best known methods and large staffs of human computers.

These mechanical brains not only calculate, however. They also remember and reason, and thus they promise to solve some very important human problems. For example, one of these problems is the application of what mankind knows. It takes too long to find understandable information on a subject. The libraries are full of books: most of them we can never hope to read in our lifetime. The technical journals are full of condensed scientific information: they can hardly be understood by you and me. There is a big gap between somebody’s knowing something and employment of that knowledge by you or me when we need it. But these new mechanical brains handle information very swiftly. In a few years machines will probably be made that will know what is in libraries and that will tell very swiftly where to find certain information. Thus we can see that mechanical brains are one of the great new tools for finding out what we do not know and applying what we do know.
Chapter 2

LANGUAGES:
SYSTEMS FOR HANDLING INFORMATION

As everyone knows, it is not always easy to think. By thinking, we mean computing, reasoning, and other handling of information. By information we mean collections of ideas—physically, collections of marks that have meaning. By handling information, we mean proceeding logically from some ideas to other ideas—physically, changing from some marks to other marks in ways that have meaning. For example, one of your hands can express an idea: it can store the number 3 for a short while by turning 3 fingers up and 2 down. In the same way, a machine can express an idea: it can store information by arranging some equipment. The Harvard mechanical brain can store 132 numbers between 0 and 99,999,999,999,999,999,999 for days. When you want to change the number stored by your fingers, you move them: perhaps you need a half second to change the number stored by your fingers from 3 to 2, for example. In the same way, a machine can change a stored number by changing the arrangement of some equipment: the electronic brain Eniac can change a stored number in $1/2000$ of a second.

LANGUAGES

Since it is not always easy to think, men have given much attention to devices for making thinking easier. They have worked out many systems for handling information, which we often call languages. Some languages are very complete and versatile and of great importance. Others cover only a narrow field—such as numbers alone—but in this field they may be remarkably efficient. Just what is a language?

Every language is both a scheme for expressing meanings and physical equipment that can be handled. For example, let us take spoken English. The scheme of spoken English consists of more than 150,000 words expressing meanings, and some rules for putting words together meaningfully. The physical equipment of spoken English consists of (1) sounds in the air, and (2) the ears of millions of people, and their mouths and voices, by which they can hear and speak the sounds of English. For another example, let us take numbers expressed in the Arabic numerals and the rules of arithmetic. The scheme of this language contains only ten digits 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 or their equivalents, and some rules for combining them. Sufficient physical equipment for this language might very well be a ten-column desk calculating machine with its counter wheels, gears, keys, etc. If we tried to exchange the physical equipment of these two languages, we would be blocked: the desk calculating machine cannot possibly express the meaningful combinations of 150,000 words, and sounds in the air are not permanent enough to express the steps of division of one large number by another.

SCHEMES FOR EXPRESSING MEANINGS

If we examine languages that have existed, we can observe a number of schemes for expressing meanings. In the table on pp. 12–13 is a rough list of a dozen of them. From among these we can choose the schemes that are likely to be useful in mechanical brains. Schemes 11 and 12 are the schemes that have been predominantly used in machinery for computing. Scheme 12 consisting of combinations of just two marks, √, ×, provides one of the best codes for mechanical handling of information. This scheme, called binary coding (see Supplement 2), is also useful for measuring the quantity of information.

QUANTITY OF INFORMATION

How should we measure the quantity of information? The smallest unit of information is a "yes" or a "no," a check mark
## Schemes for Expressing Meanings

### Example:

<table>
<thead>
<tr>
<th>No.</th>
<th>Principle of Scheme</th>
<th>Sign</th>
<th>Used in</th>
<th>Significance</th>
<th>Name of Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Sound of new word is like sound of referent</td>
<td>Bobwhite *</td>
<td>Spoken English</td>
<td>Sounds</td>
<td>Imitative; bowwow theory</td>
</tr>
<tr>
<td>2.</td>
<td>An utterance becomes a new word</td>
<td>Pooh! *</td>
<td>Spoken English</td>
<td>The speaker expresses disdain</td>
<td>Pooh-pooh theory</td>
</tr>
<tr>
<td>3.</td>
<td>New word is like another word</td>
<td>Chortle *</td>
<td>Spoken English; invented by Lewis Carroll, 1896</td>
<td>&quot;Chuckle&quot; and &quot;snort&quot; blended</td>
<td>Analogical</td>
</tr>
<tr>
<td>4.</td>
<td>Word has been used through the ages</td>
<td>Mother *</td>
<td>Spoken English</td>
<td>Female parent</td>
<td>Historical</td>
</tr>
<tr>
<td>5.</td>
<td>Picture is like referent</td>
<td></td>
<td>Egyptian; Ojibwa (American Indian)</td>
<td>Sights</td>
<td>Imitative; pictographic</td>
</tr>
<tr>
<td>6.</td>
<td>Pattern is symbol of an idea</td>
<td>5</td>
<td>English; French; German; etc.</td>
<td></td>
<td>Ideographic; mathematical; symbolic; numeric</td>
</tr>
</tbody>
</table>

### Mapping of Sounds

<table>
<thead>
<tr>
<th>No.</th>
<th>Principle of Scheme</th>
<th>Sign</th>
<th>Used in</th>
<th>Significance</th>
<th>Name of Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.</td>
<td>Object pictured has the wanted sound</td>
<td></td>
<td>Possible English</td>
<td>Picture of a knot to mean &quot;not&quot;</td>
<td>Rebus-writing; phonographic</td>
</tr>
<tr>
<td>8.</td>
<td>Pattern is a symbol for a large sound unit</td>
<td>Possible English</td>
<td>Ancient Cypriote (island of Cyprus)</td>
<td>Sign for the syllable mu</td>
<td>Syllabic-writing</td>
</tr>
<tr>
<td>9.</td>
<td>Pattern is a symbol for a small sound unit</td>
<td>5</td>
<td>International Phonetic Alphabet of 87 characters</td>
<td>The sound zh, as in &quot;measure&quot;</td>
<td>Phonetic writing; alphabetic writing</td>
</tr>
</tbody>
</table>

### Mapping of Sights or Symbols

<table>
<thead>
<tr>
<th>No.</th>
<th>Principle of Scheme</th>
<th>Sign</th>
<th>Used in</th>
<th>Significance</th>
<th>Name of Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.</td>
<td>Systematic combinations of 26 letters</td>
<td>ENIAC</td>
<td>Abbreviations, etc.</td>
<td>Initial letters of a 5-letter title</td>
<td>Alphabetic coding</td>
</tr>
<tr>
<td>11.</td>
<td>Systematic combinations of 10 digits</td>
<td>135-03-1228</td>
<td>Abbreviations, nomenclature, etc.</td>
<td>Social Security No. of a person</td>
<td>Numeric coding</td>
</tr>
</tbody>
</table>

* The preceding word is the spoken word, not the written one.
(✓) or a cross (✗), an impulse in a nerve or no impulse, a 1 or a 0, black or white, good or bad, etc. This twofold difference is called a binary digit of information (see Supplement 2). It is the convenient unit of information.

With 2 units of information or 2 binary digits (1 or 0) we can represent 4 pieces of information:

00, 01, 10, 11

With 3 units of information we can represent 8 pieces of information:

000, 001, 010, 011, 100, 101, 110, 111

With 4 units of information we can represent 16 pieces of information:

0000 0001 0010 0011
0100 0101 0110 0111
1000 1001 1010 1011
1100 1101 1110 1111

Now 4 units of information are sufficient to represent a decimal digit 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 and allow 6 possibilities to be left over; 3 units of information are not sufficient. For example, we may have:

0 0000 5 0101
1 0001 6 0110
2 0010 7 0111
3 0011 8 1000
4 0100 9 1001

We say, therefore, that a decimal digit 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 is equivalent to 4 units of information. Thus a table containing 10,000 numbers, each of 10 decimal digits, is equivalent to 400,000 units of information.

One of the 26 letters of the alphabet is equivalent to 5 units of information, for, 5 binary digits (1 or 0) have 32 possible arrangements, and these are enough to provide for the 26 letters. Any printed information in English can be expressed in about 80 characters consisting of 10 numerals, 52 capital and small letters, and some 18 punctuation marks and other types of marks; 6 binary digits (1 or 0) have 64 possible arrangements, and 7 binary digits (1 or 0) have 128 possible arrangements.

Each character in a printed book, therefore, is roughly equivalent to 7 units of information.

It can be determined that a big telephone book or a big reference dictionary stores printed information at the rate of about 1 billion units of information per cubic foot. If the 10 billion nerves in the human brain could independently be impulsed or not impulsed, then the human brain could conceivably store 10 billion units of information. The largest library in the world is the Library of Congress, containing 7 million volumes including pamphlets. It stores about 100 trillion units of information.

We can thus see the significance of a quantity of information from 1 unit to 100 trillion units. No distinction is here made between information that reports facts and information that does not. For example, a book of fiction about persons who never existed is still counted as information, and, of course, much instruction and entertainment may be found in such a source.

PHYSICAL EQUIPMENT FOR HANDLING INFORMATION

The first thing we want to do with information is store it. The second thing we want to do is combine it. We want equipment that makes these two processes easy and efficient. We want equipment for handling information that:

1. Costs little.
2. Holds much information in little space.
3. Is permanent, when we want to keep the information.
4. Is erasable, when we want to remove information.
5. Is versatile, holds easily any kind of information, and allows operations to be done easily.

The amount of human effort needed to handle information correctly depends very much on the properties of the physical equipment expressing the information, although the laws of correct reasoning are independent of the equipment. For example, the great difficulty with spoken sounds as physical equipment for handling information is the trouble of storing them. The technique for doing so was mastered only about 1877 when Thomas A. Edison made the first phonograph. Even with this
<table>
<thead>
<tr>
<th>No.</th>
<th>Physical Objects</th>
<th>Arranged in or on</th>
<th>Operated on Produced by</th>
<th>Low Core?</th>
<th>Little Space?</th>
<th>Permanent?</th>
<th>Erasable?</th>
<th>Versatile?</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>Nerve cells</td>
<td>Human brain</td>
<td>Body</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>(2)</td>
<td>Sounds</td>
<td>Air</td>
<td>Voice</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>(3)</td>
<td>Soundtracks</td>
<td>Wax cylinders, phonograph records</td>
<td>Machines and motors</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>(4)</td>
<td>Marks</td>
<td>Sand</td>
<td>Stick</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>(5)</td>
<td>Colored painting</td>
<td>Cave walls, canvases, etc.</td>
<td>Paintbrush and paints</td>
<td>✗</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
<td>x X</td>
</tr>
<tr>
<td>(6)</td>
<td>Marks, inscriptions</td>
<td>Clay, stone</td>
<td>Stylus, chisel</td>
<td>✗ ✓ x</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
<td>✓</td>
</tr>
<tr>
<td>(7)</td>
<td>Marks</td>
<td>Slate</td>
<td>Chalk</td>
<td>✓ x</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
<td>✓</td>
</tr>
<tr>
<td>(8)</td>
<td>Marks</td>
<td>Paper, parchment, etc.</td>
<td>Pen and ink, pencil</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
<td>✓</td>
</tr>
<tr>
<td>(9)</td>
<td>Letters, etc.</td>
<td>Paper, books, etc.</td>
<td>Printing press, movable type, motor, and hands</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>(10)</td>
<td>Photographs</td>
<td>Film, prints, etc.</td>
<td>Camera</td>
<td>✓ ✓ x</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>(11)</td>
<td>Letters, etc.</td>
<td>Paper, mimeograph stencil, etc.</td>
<td>Typewriter and fingers</td>
<td>✓ ✓ x</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>(12)</td>
<td>Gestures</td>
<td>Space</td>
<td>Body</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
<td>X X</td>
</tr>
<tr>
<td>(13)</td>
<td>Fingers</td>
<td>Hands</td>
<td>Body</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
<td>X X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Objects</th>
</tr>
</thead>
<tbody>
<tr>
<td>14. Pebbles</td>
</tr>
<tr>
<td>15. Knots</td>
</tr>
<tr>
<td>16. Tassels, notches</td>
</tr>
<tr>
<td>17. Beads</td>
</tr>
<tr>
<td>18. Ruled lines, pointers</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>19. Counter wheels, gears, keys, lights, etc.</td>
</tr>
<tr>
<td>20. Punched cards and paper tape</td>
</tr>
<tr>
<td>21. Relays</td>
</tr>
<tr>
<td>22. Electronic tubes</td>
</tr>
<tr>
<td>23. Magnetic surfaces: wire, tape, discs</td>
</tr>
<tr>
<td>24. Delay lines: electric, acoustic</td>
</tr>
<tr>
<td>25. Electrostatic storage tubes</td>
</tr>
</tbody>
</table>

✓ ✓ yes, very.
✓ yes, adequately.
✗ not generally.
✗ ✗ not at all.
advances, no one can glance at a soundtrack and tell quickly what sounds are stored there; only by turning back the machine and listening to a groove can we determine this. It was not possible for the men of 2000 B.C. to wait thousands of years for the storing of spoken sounds. The problem of storing information was accordingly taken to other types of physical equipment.

What are the types of physical equipment for handling information, and which are the good ones? In the table on pp. 16-17 is a rough list of 25 types of physical equipment for handling information. √√ means "yes, very;" √ means "yes, adequately;" × means "not generally;" ☓ means "not at all."

For example, our fingers (see No. 13) as a device for handling information are very expensive for most cases. They take up a good deal of space. Certainly they are very temporary storage; any information they may express is very erasable; and what we can express with them alone is very limited. Yet, with a typewriter (see No. 11), our fingers become versatile and efficient. In fact, our fingers can make 4 strokes a second; we can select any one of about 38 keys; and, since each key is equivalent to 5 or 6 units of information, the effective speed of our fingers may be about 800 units of information a second.

LANGUAGES OF PHYSICAL OBJECTS

The use of pebbles (see No. 14) for keeping track of numerical information is shown in the history of the words containing the root calc- of the word calculate. The Latin word calcis meant pertaining to lime or limestone, and the Latin word calculus derived from it meant first a small piece of limestone, and later any small stone, particularly a pebble used in counting. All three of these meanings have left descendants: "chalk," "calcite," "calcium," relating in one way or another to lime; in medicine, "calcus," referring to stones in the kidneys or elsewhere in the body; and in mathematics, "calculate," "calculus," referring to computations, once done with pebbles.

The pebbles, and the slab (for which the ancient Greek word is optron) on which they were arranged and counted, were later replaced, for ease of handling, by groups of beads strung on rods and placed in a frame (see No. 17). These constituted the abacus (see Supplement 2 and the figure there). This was the first calculating machine. It is still used all over Asia; in fact, even today more people use the abacus for accounting than use pencil and paper. The skill with which the abacus can be used was shown in November 1946 in a well-publicized contest in Japan. Kiyoshi Masuzaki, a clerk in the Japanese communications department, using the abacus, challenged Private Thomas Wood of the U.S. Army, using a modern desk calculating machine, and defeated him in a speed contest involving additions, subtractions, multiplications, and divisions.

The heaps of small pebbles, the notches in sticks, and the abacus had the advantage of being visible and comparatively permanent. Storing and reading were relatively easy. They were rather compact and easy to manipulate, certainly much easier than spoken words. But they were subject to disadvantages also. Moving correctly from one arrangement to another was difficult, since there was no good way for storing intermediate steps so that the process could be easily verified. Furthermore, these devices applied to specified numbers only. Also, there was no natural provision for recording what the several numbers belonged to. This had to be recorded with the help of another language, writing.

The language of physical objects was picked up from obscurity by the invention of motors and the demands of commerce and business. Commencing in the late 1800's, desk calculating machines (see No. 19) were constructed to meet mass calculation requirements. They would add, subtract, multiply, and divide specific numbers with great accuracy and speed. But until recently they still were adjuncts to the other languages, for they provided figures one at a time for insertion in the spaces on the ledger pages or calculation sheets where figures were called for.

Beginning in the 1920's, a remarkable change has taken place. Instead of performing single operations, machines have been developed to perform chains of operations with many kinds of information. One of these machines is the dial telephone; it can select one of 7 million telephones by successive sorting according to the letters and digits of a telephone number. Another of these machines is a fire-control instrument, a mechanism for
controlling the firing of a gun. For example, in a modern anti-aircraft gun the mechanism will observe an enemy plane flying at several hundred miles an hour, convert the observations into gun-aiming directions, and determine the aiming directions fast enough to shoot down the plane. **Punch-card machinery**, machines handling information expressed as punched holes in cards, enable the fulfillment of social security legislation, the production of the census, and countless operations of banks, insurance companies, department stores, and factories. And, finally, in 1942 the first mechanical brain was finished at Massachusetts Institute of Technology.

**THE CRUCIAL DEVICES FOR MECHANICAL BRAINS**

Let us consider the two modern physical devices for handling information which make mechanical brains possible. These are **relays** and **electronic tubes** (Nos. 21 and 22). The last three kinds of equipment listed in the table (magnetic surfaces, No. 23; delay lines, No. 24; and electrostatic storage tubes, No. 25) were not included in any mechanical brains functioning by the middle of 1948. The discussion of them is therefore put off to Chapter 10, where we talk about the future design of mechanical brains.

Figure 1 shows a simple relay. There are two electrical circuits here. One has two terminals—Pickup and Ground. The other has three terminals—Common, Normally Open, and Normally Closed. When current flows through the coil of wire around the iron, it makes the iron a magnet; the magnet pulls down the flap of iron above, overcoming the force of the spring. When there is no current through the coil, the iron is not a magnet, and the flap is held up by the spring. Now suppose that there is current in Common. When there is no current in Pickup, the current from Common will flow through the upper contact, to the terminal marked Normally Closed. When there is current in Pickup, the current from Common will flow through the lower contact, to the terminal marked Normally Open. Thus we see that a relay expresses a "yes" or a "no," a 1 or 0, a binary digit, a unit of information. A relay costs $5 to $10. It is rather expensive for storing a single unit of information. The fastest it can be changed from 1 to 0, or vice versa, is about \( \frac{1}{100} \) of a second.

Figure 2 shows a simple electronic tube. It has three parts—the Cathode, the Grid, and the Plate. The Grid actually is a coarse net of metal wires. Electrons can flow from the Cathode to the Plate, provided the voltage on the Grid is such as to permit them to flow. So we can see that an electronic tube is a very simple on-off device and expresses a "yes" or a "no," a 1 or 0, a binary digit, a unit of information. A simple electronic tube suitable for calculating purposes costs 50 cents to a $1, only \( \frac{1}{100} \) the cost of a relay. It can be changed from 1 to 0, or back again, in 1 millionth of a second.

Relays have been widely used in the mechanical brains so far built, and electronic tubes are the essence of Eniac.

In the next chapter, we shall see how physical equipment for handling information can be put together to make a simple mechanical brain.