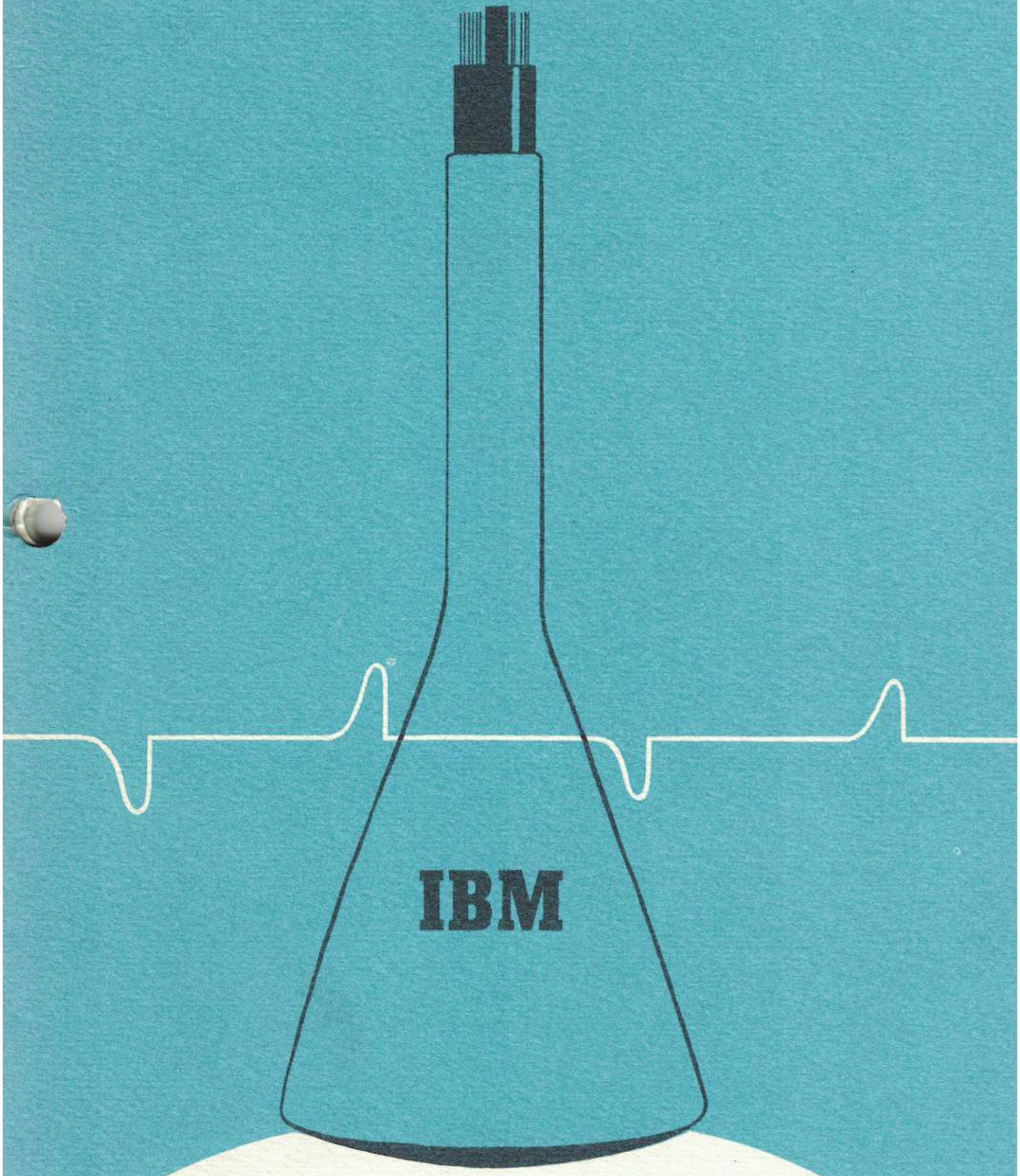
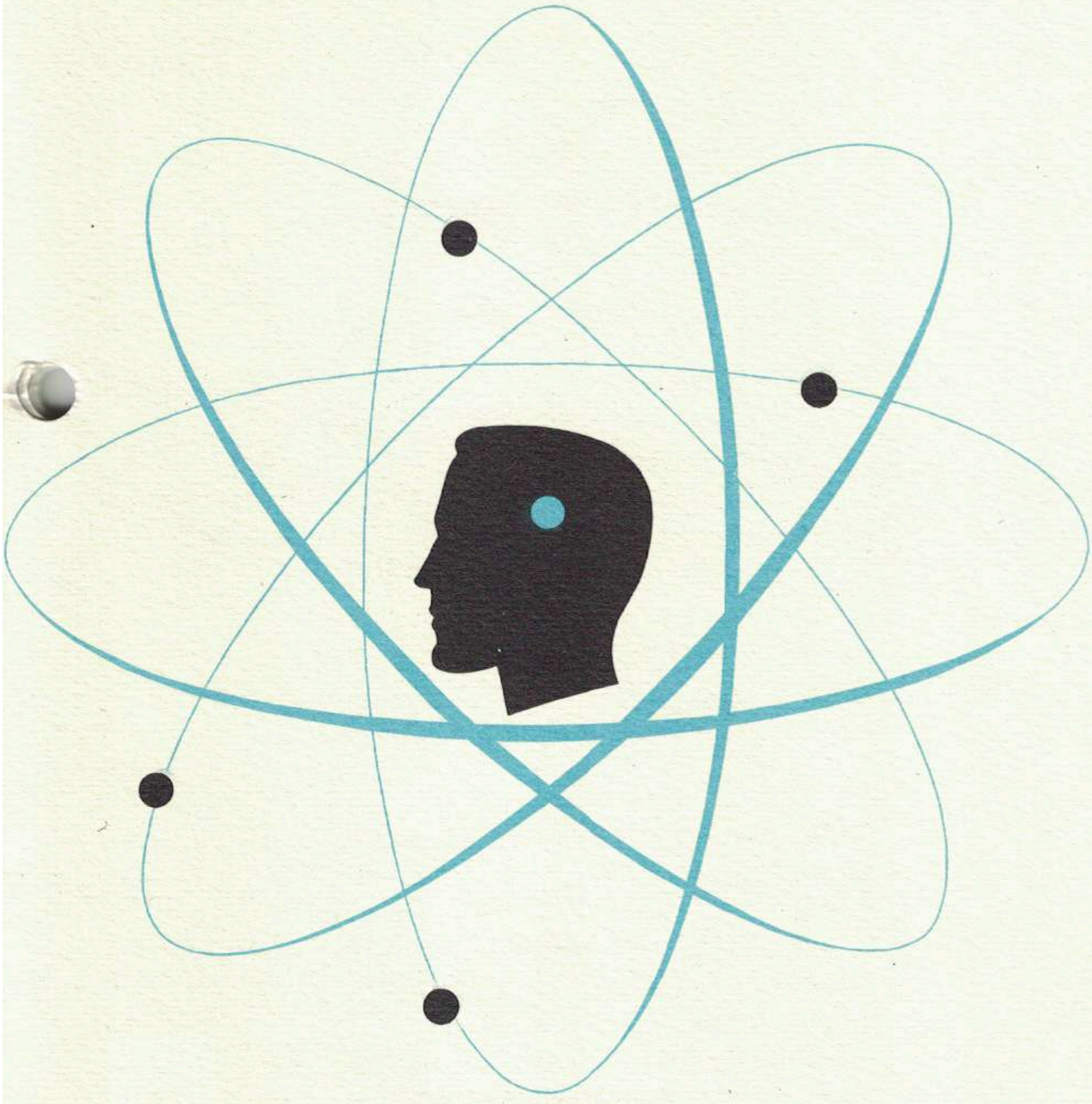
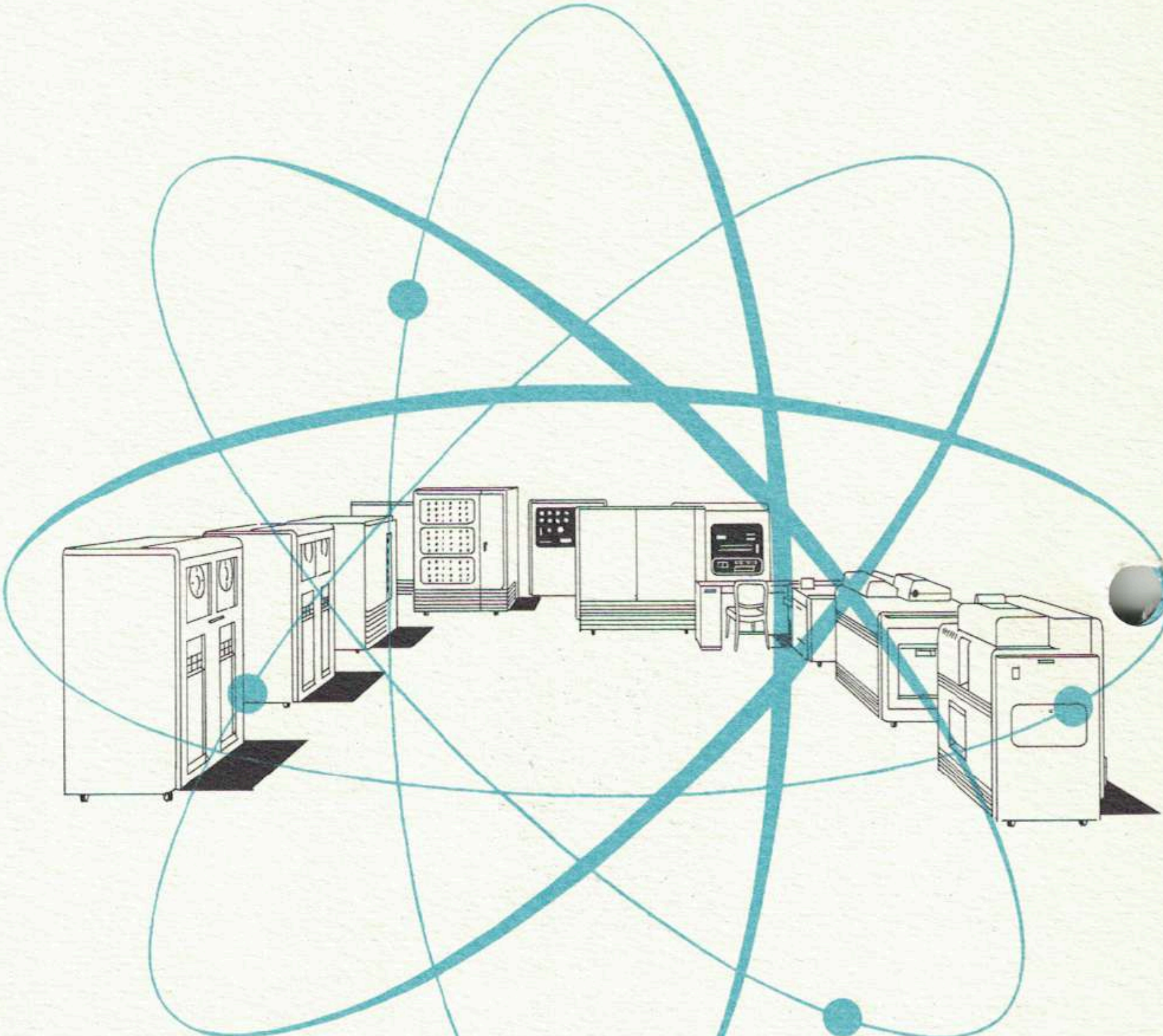


Light on the Future

Contents



Light on the Future



It took men millions of years to invent and recognize the usefulness of the wheel. But, in a single generation, our scientists and manufacturers have filled the world with more new products than have all the generations which preceeded them. To these men, no series of recent technological developments is more promising than those involving machines capable of electronic processing of scientific and business data.

Some of this promise already has been turned into reality by IBM's pioneering work in developing and producing a series of electronic machines which have made significant contributions to government, science, and industry. These machines did not "just happen". They were developed as the result of intensive and continuing scientific research.

IBM built the first large-scale digital calculator, the Automatic Sequence Controlled Calculator, which has operated successfully at Harvard University since 1944. This calculator, by proving what a giant machine could do, is credited with starting the present lively developments in the field of "giant brains."

In 1948, IBM installed its first large *electronic* digital calculator, the Selective Sequence Electronic Calculator, in New York. Since then, these same electronic principles have been applied to thousands of smaller electronic calculators.

And, in 1953, just five years after this first "giant" electronic digital calculator was installed, IBM proudly introduced its Type 701 Electronic Data Processing Machines —twenty-five to thirty times more powerful in speed and capacity than the S.S.E.C. — and produced on a production-line basis.

Designed and built for the special computing needs of scientists and engineers, these machines will be used to meet the needs of our country's defense organizations. They utilize, however, principles and components which will be incorporated in the business machines — the IBM machines — of tomorrow.

It is the purpose of this booklet to describe the significant principles and components of these machines.

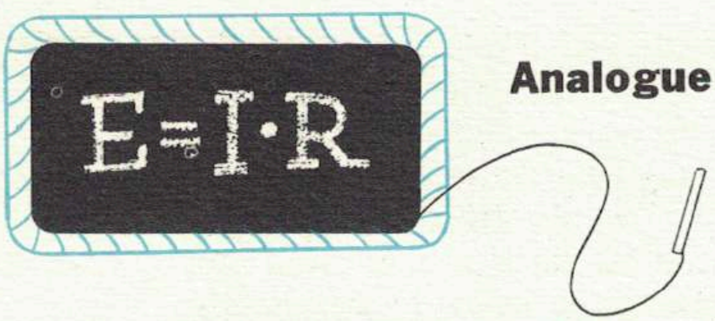
1

Two Families of Computers

Two kinds of computers are being talked about today. They are frequently lumped together under the heading of "mechanical brains" but they are very different in construction and application.

One is *analogue*.

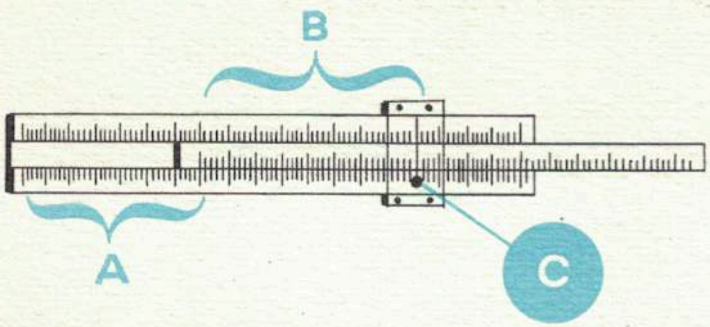
The other is *digital*.



Analogue Computers

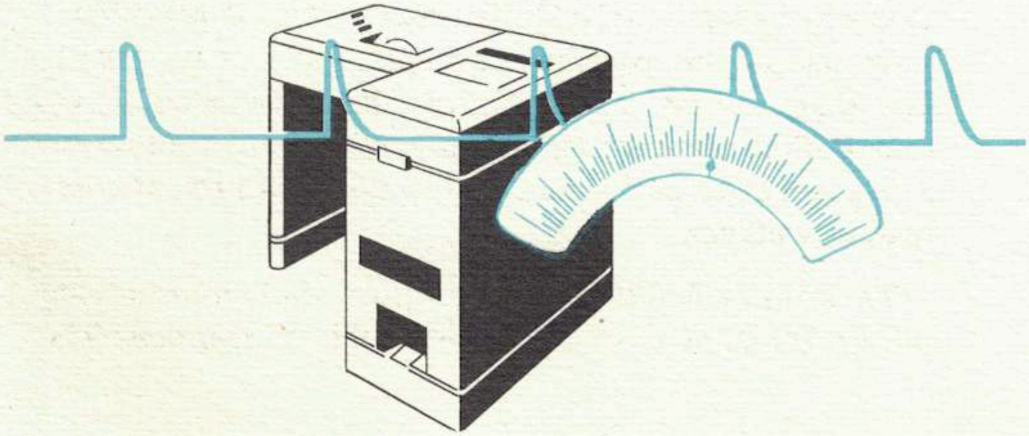
Analogue computers are so named because they operate by setting up physical situations which are similar (analogous) to mathematical situations. For example, Ohm's Law, one of the fundamental natural laws of electricity, says that "Voltage equals Current times Resistance." By substituting different values as currents and resistances, it is possible to perform multiplications with the answers read as voltages.

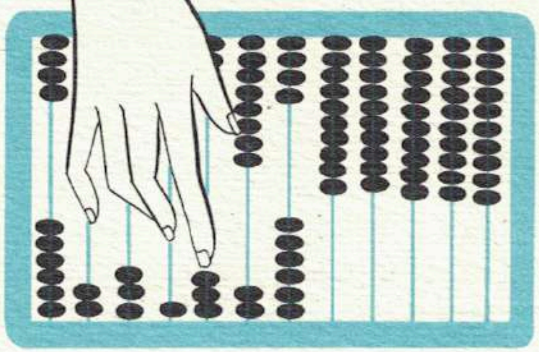
Thus, an analogue computer is essentially a measuring device. It can be mechanical, electrical, or electronic. The speedometer in your automobile is one simple kind of analogue computer. It converts the rate of turning of a shaft into a numerical approximation of speed. A slide rule belongs to the analogue family. Distances between points on the "slip stick" are read numerically in such a way that they give the approximate answers to multiplications, divisions, square roots, and so on.



The IBM Test Scoring Machine is an analogue computer. It measures the flow of current at constant voltage passing through the pencil marks on an examination answer sheet. The score on the examination is directly proportional to the quantity of current flowing through the circuit resistances. This quantity is measured by a meter, calibrated so that the numerical score can be read directly.

Many of the devices used for fire control and navigation are analogue computers, as are the differential analyzers in some engineering laboratories. Analogue computers are often used for the simulation of a physical problem, such as the theoretical flight of an airplane with specific design characteristics, or the load upon the distribution network of an electric utility.

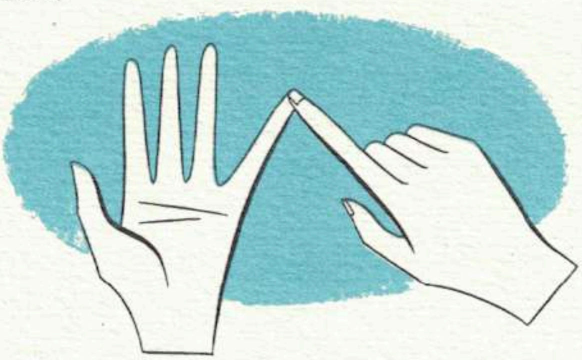




Digital Computers

Digital computers have come down through the ages, first in the form of the abacus, then the first crude adding machine invented by Pascal, then the ancestor of the desk calculator invented by Leibnitz.

The modern digital computers can perform very long sequences of computation automatically, making decisions and referring to memory as they go along. Their input-output facilities are capable of handling a steady stream of information. They are general-purpose machines capable of solving any mathematical problem that can be expressed numerically. It is these abilities that have made them such valuable tools to scientists and businessmen.



Digital computers owe their name to the 10 *digits* on our two hands. *Counting* on the fingers is one way to obtain exact answers to simple arithmetic. Because we have *10* digits instead of twelve, or six, or eight, most computation is based on the familiar *decimal* system.

There are other symbols and number systems. For example, years ago the Romans had their own system of numbers. Today, it is obsolete and is seen only occasionally. However, another number system, increasing in importance, is the binary number system. If we had only two fingers, our arithmetic might very well be based on the binary system, which uses only two digits, 0 and 1.

The following chart compares the familiar decimal numbers from zero to thirteen with the corresponding symbols in the important binary and obsolete Roman systems:

Decimal	*Binary*	*Roman*
0	0	
1	1	I
2	10	II
3	11	III
4	100	IV
5	101	V
6	110	VI
7	111	VII
8	1000	VIII
9	1001	IX
10	1010	X
11	1011	XI
12	1100	XII
13	1101	XIII

Note that in the binary system each time the digit 1 is moved one position to the left, its value doubles.

Some of the fastest electric and electronic devices do have the equivalent of two fingers. Since only two digits are required, binary numbers may be represented in electronic equipment by vacuum tubes – being either *on* or *off*. That is why binary arithmetic is so popular with computer engineers. The "on" condition may represent "1", and "off" may represent "0". For instance, assume four vacuum tubes, designated A, B, C, and D from left to right. The condition of A, B, and D being "on" and C "off" would, according to the table, represent the binary figure 1101, or represent the decimal figure 13. Fortunately, machines can be designed to take in decimal numbers, convert them to binary, compute in binary, and then deliver the answers in decimal – an automatic operation which makes everybody happy.

2 Organization of Digital Computers

A digital computer, as the term is used here, embodies in *one* machine the following components: input, storage, arithmetic, control, output.

1 *Input*

A computer must have input facilities able to handle and read information from some physical medium. Such devices, for example, may work with punched cards, punched paper tape, or magnetic tape.

2 *Storage*

The internal storage of a computer consists of a group of electro-mechanical or electronic devices. There, information is stored until the computer is ready to use it. It is readily accessible, it can be referred to once or many times and also be replaced whenever desired. The information held here can be original data, intermediate answers, or instructions. Each storage location is identified by its own individual number or symbol which is called an "address." "Access time" is the length of time required to "call" a number from a storage unit and make it available to any other part of the computer.

3 Arithmetic

This unit is capable of addition, subtraction, multiplication and division. More complex calculations are always made up of combinations of these basic operations. Also, this unit can distinguish between positive, negative, and zero values, and pass this information on to other parts of the computer.

The arithmetic unit operates on either a *parallel* or a *serial* basis. A *parallel* computer has an arithmetic unit which operates on all the digits of a factor simultaneously. This is like the familiar desk adding machine. A *serial* computer takes digits, one at a time, feeding the individual pieces of the result back to storage until the operation is completed. This is similar to the way we solve an arithmetic problem with paper and pencil.

4 Control

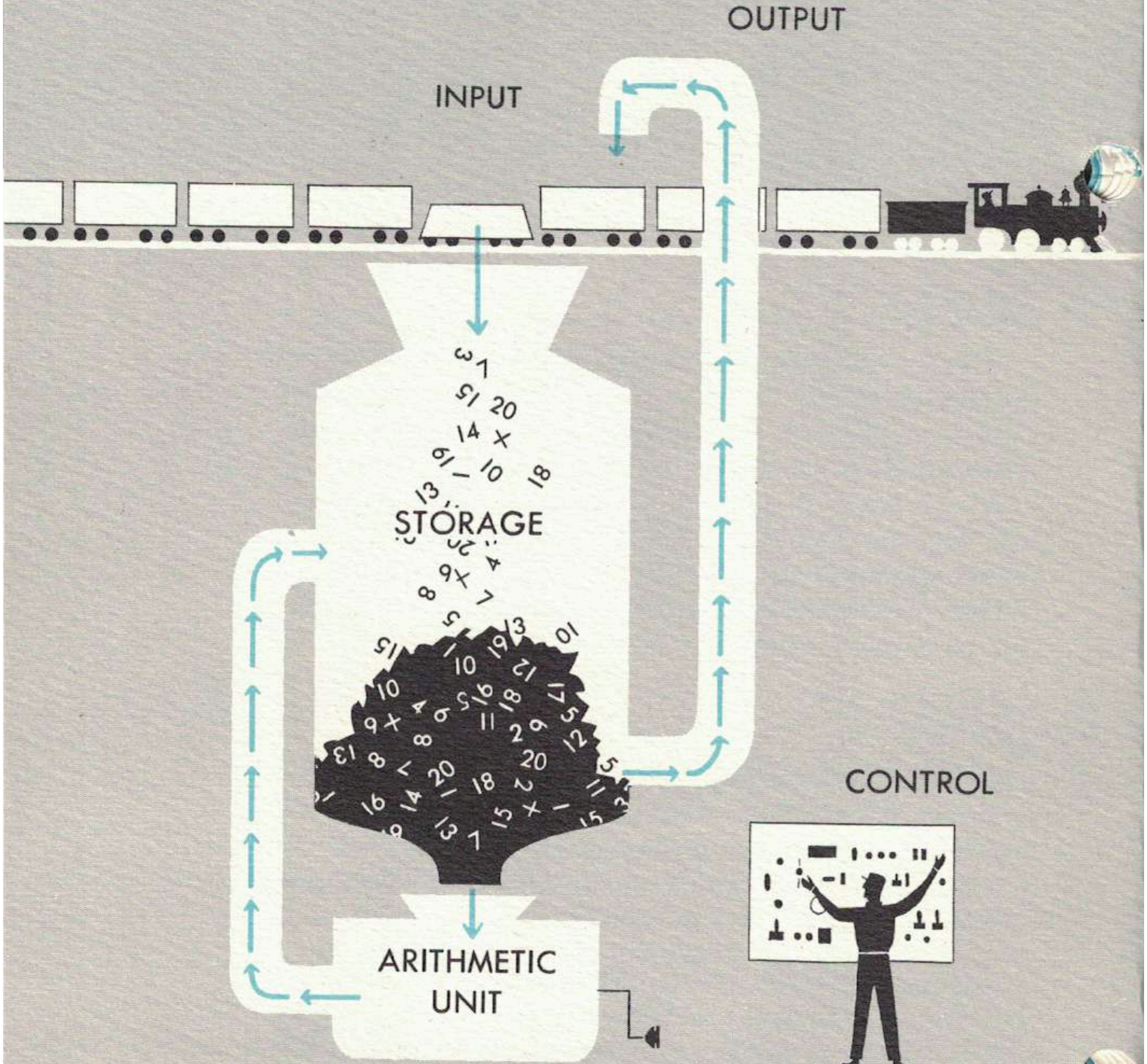
The calculations and routing of the factors are performed under the direction of a "control" or "program" unit. This unit gets its instructions, one at a time, from their locations in storage. It executes each instruction until the entire problem is completed. Each instruction not only specifies the functional operation which is to be performed; it also gives one or more addresses of the factor or factors to be operated on and the address where the result is to be stored.

5 Output

Having done its work, the calculator now writes the answers. This can take the form of punching a card, recording on tape, or printing. Because they print an entire line of information at one time, IBM printing devices are well-suited to high-speed computers.

Components 1, 3, and 5 correspond to the "3-R's" – reading, 'riting, and 'rithmetic. Component 4 handles the "3-W's" – what, when, and where. Component 2 is like the blackboard or work paper for instructions and intermediate answers.

Functional Principles from a Different Perspective



The organization of these components to form a computer is quite familiar. For example, in the usual desk calculator, the keyboard is the "input"; the mechanical counters perform the functions of "storage" and "arithmetic"; the add, subtract, multiply, total, and other keys provide "control"; and the printed tape is the "output."

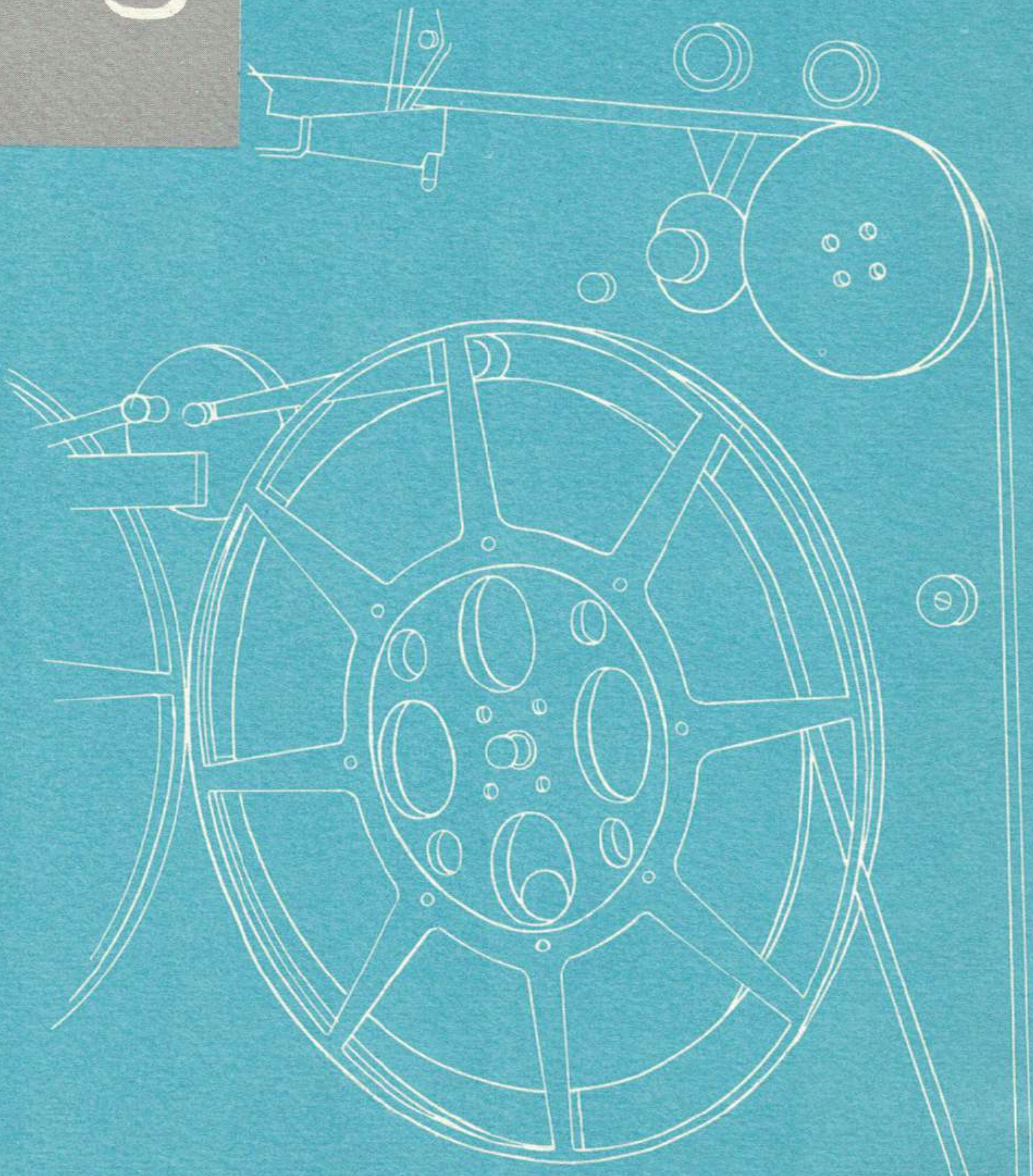
In the electronic system all these units are electrically connected and the system may be controlled to perform automatically a sequence of functions, such as data input, data storage, comparisons, arithmetic functions, and output of results. This is one of the most significant features of an electronic system, because it means that the system offers the possibility of accomplishing a complete series of operations – from raw data input to final results output – automatically without manual movement of partially complete information from one unit to another.

Essentially, then, this is based on the automatic internal transmission of *data* from component to component, until final results are produced. The function that each component is to accomplish, and the sequence of accomplishment, must be told to the system in a series of "instructions." These instructions are then stored within the memory of the system and are automatically referred to, as required, to complete the entire series of operations. This group of instructions is referred to as the "stored program" (more about this later).

IBM electronic data processing systems will provide both punched card input and output units. Where an application requires retention of the "unit record" feature of cards, then these units may be used, in conjunction with the other types of inputs and outputs, to introduce data into the system from files of punched cards or to record output data of the system directly into punched cards.

High-speed, line-at-a-time printers, capable of alphabetic, numerical, and special character recording, round out the equipment into a fully-integrated electronic system. Final records and reports can therefore be produced from the introduction of original data into the system.

3 New Developments



The new developments which loom so large on the horizon are, for the most part, devices for the storage of information. These storage components, because of their capacity, speed, and flexibility, have made practicable new approaches to the internal organization of machines; that is, the ways in which components may be linked together and controlled. The engineers also have been able to increase the speed of calculation by improved arithmetic circuits; but, by and large, it is the storage components and their effects on organization which are receiving the most attention.

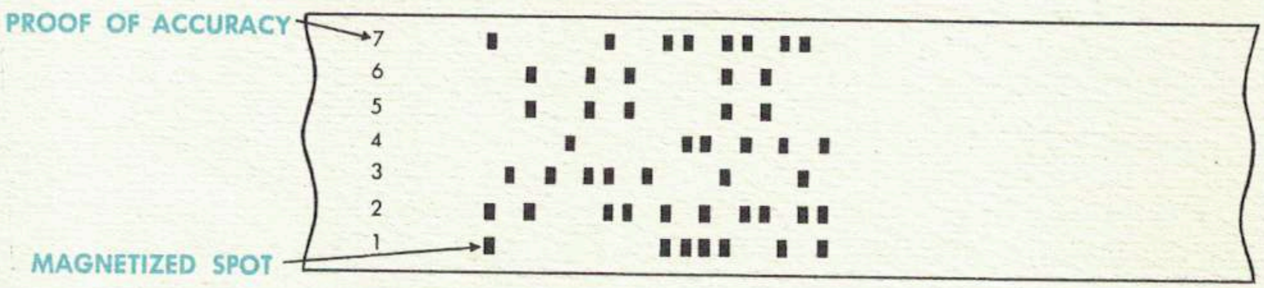
MAGNETIC TAPE

One of the newest kinds of input and output media is magnetic tape. Many radio programs and most phonograph records are now first recorded on tape, and there is even talk of tape recording of television. Like punched paper tape, magnetic tape is a continuous medium. Punched paper tapes have made important contributions in such fields as railroad, stock brokerage, and inventory accounting. The magnetic record is, of course, much faster and more compact and, therefore, opens up new areas for possible use. It also requires more elaborate equipment.

The magnetic tape is usually ½″ wide, and made of plastic or metal. The tape must have a surface coated with a material which is easily magnetized and demagnetized. Like the familiar punched paper tape, the magnetic tape is divided into parallel channels or "tracks" along the length of the tape. A typical tape might have seven channels, six of them used for storing the coded representations of numbers, letters, or symbols. The remaining channel would be used for a system of checking the accuracy of reading and writing (called a redundancy check).

Seven reading-writing devices called "heads" are spaced across the tape, one for each channel. The heads are tiny electromagnets, wound with both a read-coil and a write-coil. When writing on the tape, current passing through the write-coils sets up magnetic fields in the appropriate channels of the tape. For reading, the process is reversed. The magnetic fields on the tape induce pulses of current in the read-coils of the heads. These pulses are electronically amplified and taken into the machines as characters.

A particular reel of tape is either being read or written on, not both, in any one pass through the tape unit. It can, however, be used one time for reading and the following time for writing, if there is no need to save the previous data once it has been fed into the processing machine. A reel of tape can be used over and over hundreds of times. Writing new information automatically erases what was written in a previous operation.

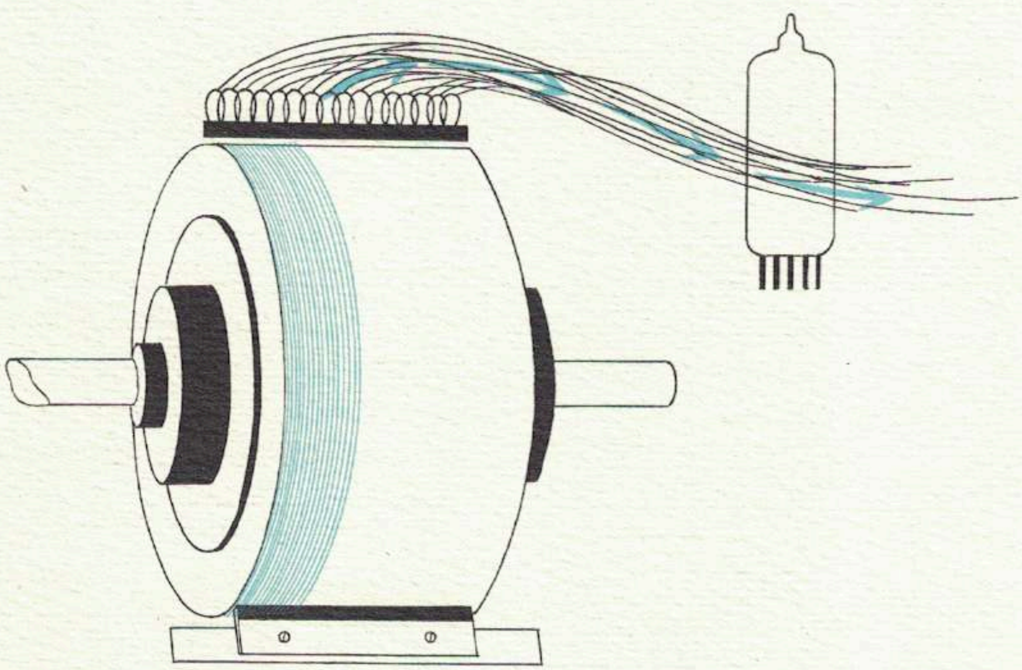


The tape can contain, for example, a series of unit records, one following along behind another. Because the magnetic recording is closely packed, a single reel of tape may contain many thousands of unit records – the exact number depending upon the size of each record. The longer the record to be written on tape, the fewer the number of records per reel of tape. As many as 20,000 records of 80 digits each on a single 12-inch diameter reel (3,000 feet of tape) is entirely possible. Compactness, therefore, is one of the most important things that tape has to offer.

The unit records on tape can be of any length – 50 digits, 100 digits, or 1,000 or more digits, if the application requires it. The length of the unit record is completely flexible, although records of the same type generally will be the same length.

A data processing machine can have a number of separate tape units attached to it. Thus, it is possible to introduce data from several master and detail files in the same operation, with records selected intermittently from the various tapes as required by the application. Additional tape units can be utilized to write new records resulting from the processing. It is this "multiple file processing" feature, coupled with the great speed of tape reading and writing that sets the electronic data processing system apart from other systems. These features permit us to take advantage of the lightning-like electronic speed of the control and arithmetic components of the system. Input and output rates are balanced to the rate of internal processing.

It is important to note, however, that the information recorded on the magnetic tape is not visible. Also, it is not practical to change one digit or one unit record or insert additional information without making a new tape.



MAGNETIC DRUM

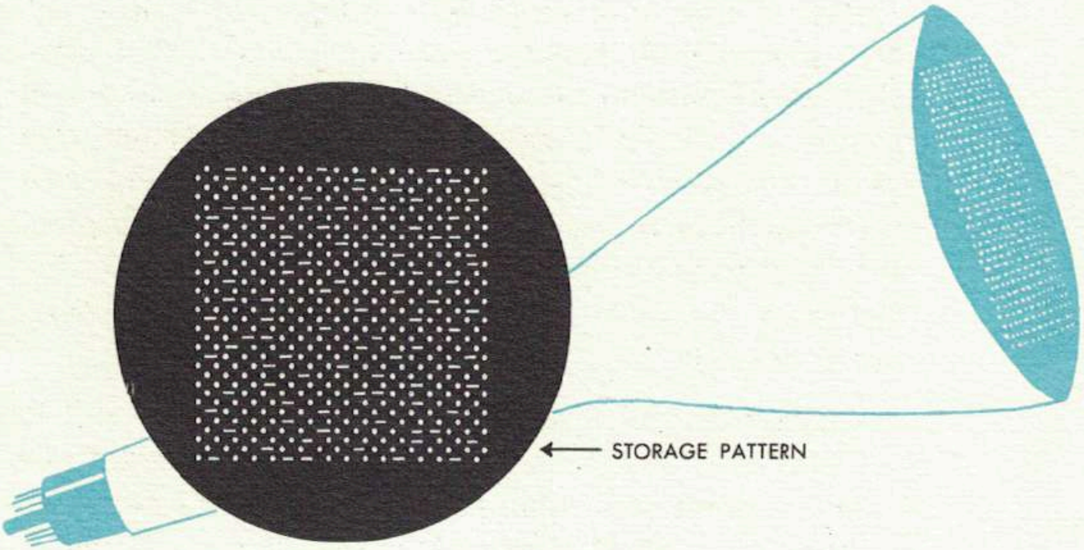
Another new development is the magnetic drum. The idea is not new. The principles have been known since the end of the last century, but it is comparatively recently that magnetic recording has become practicable. Earlier we discussed recording on magnetic tape. Essentially the same thing, with important differences, can be accomplished with drums.

If you were to take a length of tape, cut it into, say, fifty pieces, each about a yard long, and fasten them side-by-side around the outside of a cylinder, you would have, in principle, a magnetic drum. Each channel on each strip of tape would be called a "track," and each track would have its own reading-writing head. In practice, instead of using tape as the magnetic material, the engineers use other materials which, for this purpose, are even better.

Another way of looking at a drum is to compare it to a blackboard. In arithmetic problems, the factors to be added, subtracted, multiplied, or divided are often written on a blackboard while the problem is being solved. The blackboard, therefore, serves as a medium of storage which may be erased when the information is no longer required. Further, any data recorded may be referred to at random, as needed. So it is with magnetic drums except, of course, that drums are automatic, far more compact, and much faster.

The drum is mounted on a shaft. A motor rotates it, causing the surface to travel past the heads at high speed. Obviously, the drum cannot hold as much information as a reel of tape, simply because it doesn't have as great a total magnetic surface, or area. But it does have one big advantage over tape. Depending upon its size, it can store from 5,000 to upwards of 100,000 characters, and each of these can be read or written in a few thousandths of a second. It takes much longer than this to start from one end of a reel of tape and find a number which may be near the other end.

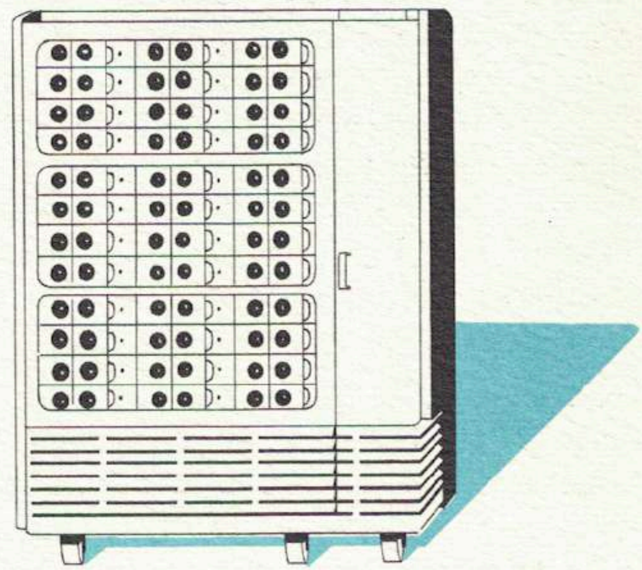
A drum revolves at upwards of 3,000 revolutions per minute – a peripheral speed of over 100 miles an hour – and the control unit can switch to the read-write head for any track almost instantly. This means that all the information stored on a drum is available over 3,000 times every minute, and that any information can be obtained in a few thousandths of a second.



ELECTROSTATIC STORAGE

Fast as it is, magnetic recording is still not fast enough for everything the engineers have in mind. Consequently, IBM has done a great deal of work on what is called "electrostatic storage"; that is, the recording of information in the form of electrical charges on the face of a cathode ray tube. This is the same basic type of tube as the picture tube in a television set. It is considerably smaller and the "picture" it stores is a pattern of dots and dashes. These dots and dashes represent characters in the same way as the fields in magnetic recording.

There are two big advantages of electrostatic storage. It is one of the fastest of any type known, doing its job in a few millionths of a second, and it is capable of what is called "instantaneous random access." This is not as complicated as it sounds. It means that the electronic beam which reads and writes on the face of the tube can go directly to any given "address" without having to scan the entire tube in a fixed sequence. Other types of storage, such as drums, have to wait until the desired piece of information passes by the reading-writing device. Therefore, since the control and arithmetic components of the system are capable of operating at electronic speeds, if all the factors of a problem are stored on a drum, the arithmetic component would have to wait for the desired information to pass the reading-writing device. To prevent this delay, electrostatic storage is used to store data required immediately by the control and arithmetic components, because the cathode ray tubes also operate at electronic speeds. Drums are normally used to store information which is not needed "instantaneously".



THE STORED PROGRAM

"Program" is a quick way to say "series of instructions." A program spells out in complete detail exactly what a machine is to do under every conceivable combination of circumstances. If some instruction is omitted from the program, the machine is completely stumped when it comes to that part of a problem. Far from being "super-brains," the machines do only what you tell them to, and if you have forgotten something they are helpless.

Because these machines operate on numbers or "digits", their instructions are numbers also. One number will tell them what operation to perform, another will tell them where the factors are stored, and still another will tell them what to do with the answer. All of the instructions, in the proper sequence necessary to accomplish a given application, form the "stored program." For example, a very simple "stored program" (using a "single address" type of coding for each instruction) may look like this:

	Operation Code	Storage Location
Instruction #1	3	1050
Instruction #2	3	1025
Instruction #3	2	0086
Instruction #4	4	0158

Instruction #1 says "add" (operation code 3) the factor stored within the machine in location number 1050. Instruction #2 says "add" the factor stored within the machine in location number 1025. Instruction #3 says "subtract" (operation code 2) the factor stored in location number 0086. Instruction #4 says "store the result" (operation code 4) of the two additions and the one subtraction in storage location 0158. The four instructions, together, form the "stored program."

The number of instructions required for the complete solution of a problem may be a few hundred, or many thousands, depending upon the problem. They are stored in the internal memory or storage unit of the calculator. The machine refers to them one after the other. Or, it can be instructed to skip over certain instructions this time, and to skip over others next time.

What does this mean in terms of applications? For one thing, it will enable machines to handle most, if not all, of the exceptions to a standard procedure that are now thrown out of a system for manual handling. The machine may be able to remember the proper handling (assuming you thought of it first) for almost any kind of a situation that comes along. And, of course, such machines will be able to handle longer and more complicated patterns than present models, good as they are.

A machine which can give more commands than a whole army of sergeants obviously has a great future.

4

What's Next?

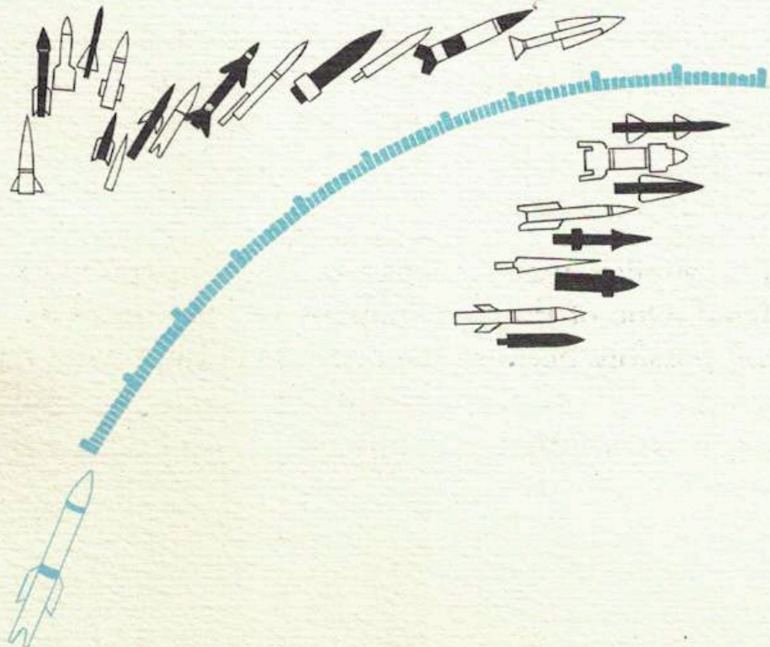
Theoretically, machines can be built to perform almost any action – tying a shoestring, for example. If this seems far-fetched, it is because you probably are picturing a person tying his own shoestring, and the concept of a machine doing that chore seems ludicrous. If, however, we broaden the picture to that of an assembly line, where a workman is busily tying the strings on thousands of shoes – hour after hour – the entire viewpoint changes and we now visualize a machine to do the job.

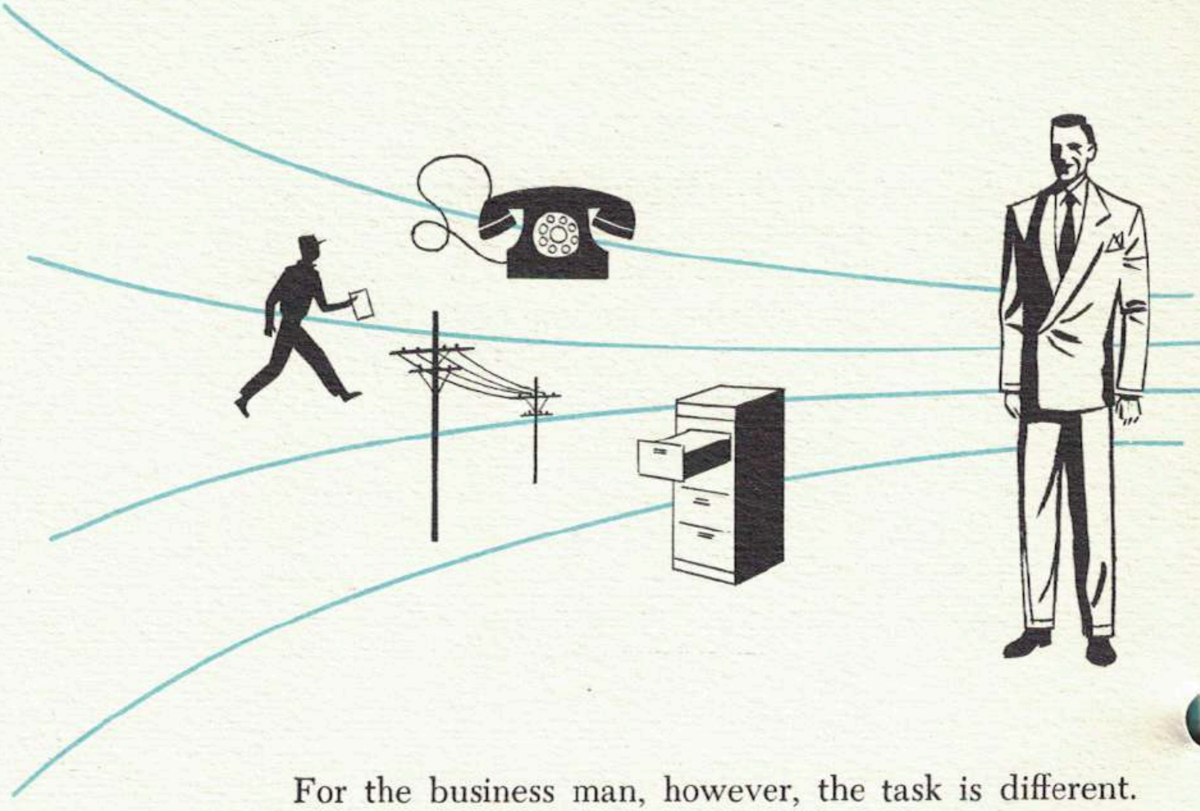
The key to that situation is *repetition* and *consistency*. Thus, functions are mechanized when they are sufficiently repetitive and consistent. We might say that consistency makes the machine possible, and repetition makes it practical (or economical).

In the factory, where mechanization first began, operations being performed over and over again in a similar manner were quite obvious, and machines were built to do them. The drill press, lathe, milling machine, and grinder are examples.

In a similar way, mechanization of paperwork has followed. One of the first "paperwork" machines was the stamp, possibly because the operation of applying a date or name is so obviously repetitive – and consistent. Other mechanization was applied – recording, sorting, adding, subtracting, filing, and many others. The IBM Accounting Machine is a good example of the multi-function application. It matches one thing against another, selects, adds, subtracts, records, and posts (by automatic positioning of forms) – all at the same time. This evolution of the "paperwork" machine has reached the point today where the problem lies not so much in designing and building the machine as it does in controlling and applying it. The appearance of electronic devices in this picture has not changed this basic problem. The speed of the electron, though, and our growing ability to direct it, is now making it possible to perform some of these functions in a fraction of the time required earlier.

It was natural that these developments were first applied to the function of arithmetic. Already being handled by multi-function machines, requiring a minimum amount of physical movement, and involving a high degree of consistency and repetition, arithmetic gained a head start in electronics application. Because this kind of arithmetic is greatest in the field of scientific calculation, development has been more pronounced in that direction. Here, arithmetic, or, more accurately, calculation is applied to a relatively small amount of original data. In solving a guided missile trajectory problem, for example, millions of arithmetic operations are performed on a few hundred starting factors – and the term "computer" accurately defines the machine needed.





For the business man, however, the task is different. He must "process" vast quantities of original data, which, because they start in different forms and come from different directions, are in all sizes, shapes, and conditions – and cannot be simulated as easily in neat, consistent "numbers" as can the scientist's source data. Because the very basis of accounting is putting "like" things together, he must classify and rearrange it, visually refer to it, write it down over and over again, do arithmetic with it, and store it for years in many different "packages." Thus, the problem becomes one of data processing, rather than computing.

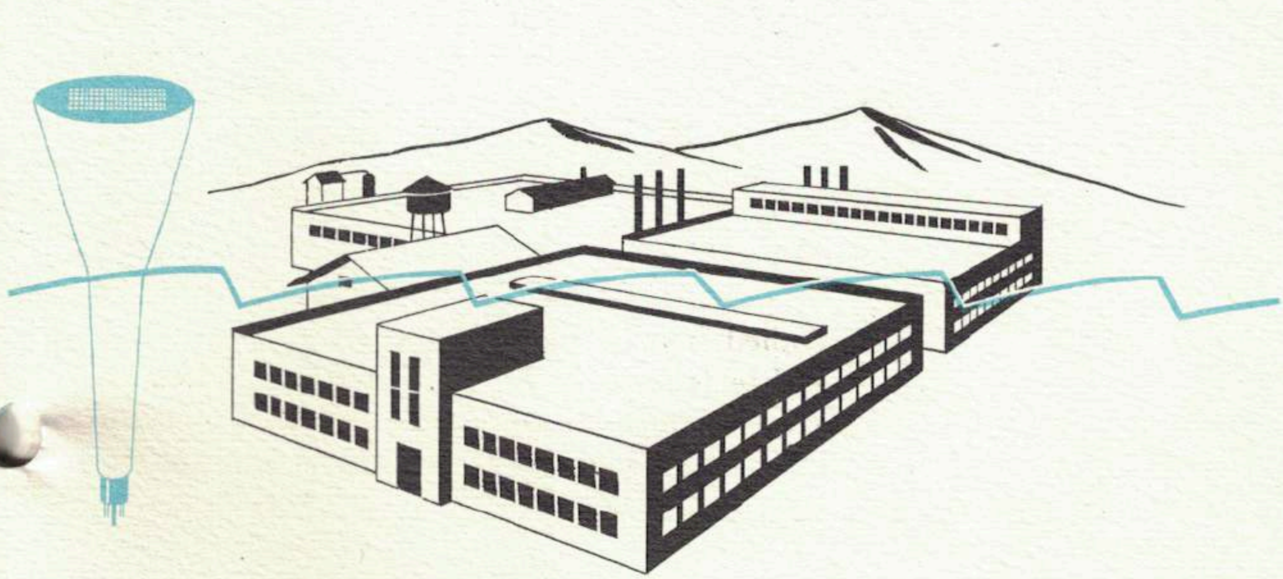
The need for increased mechanization of record-keeping has long been recognized by forward-looking executives. To hasten its adoption, they increased their efforts in methods study, procedure analysis, operator training, work control, machine and clerical loading, scheduling, application of codes, and other related activities.

In business machine applications electronics offer, other than speed, only one new basic technique, which might be called "inter-communication." Present machine methods utilize individual units for different functions, and require physical transportation of machine-read data from one unit to another. The electronic devices described earlier provide an internal method for transporting data between functions. This may be accomplished in what appears to be a single machine loading. In effect, however, it is not totally different from multiple machine processing – because each step in the procedure must be predetermined and "programmed." For example, procedure "decisions" and exceptions to handle irregularities or variables, now accomplished normally by human intervention as they occur, would have to be predetermined and programmed in electronic data processing. Thus, the requirement for determining procedures in the fullest detail will be emphasized, not reduced.

To handle the paperwork job for business, however, electronic devices must do more matching, selecting, arranging, writing, and filing than they do adding, dividing, or squaring. IBM engineers are today designing, building, and testing devices to do these jobs – and combining them into multi-function units.

When business machines of this kind are available, it is logical to expect that those organizations that have developed their control and application of present-day machines to the highest degree will be in the best position to utilize the faster electronic units.

The successful application of these faster, more versatile business machines of tomorrow rests squarely upon the ingenuity and capability being developed in applying the machines of today.



Glossary

Access Time	That time required to call a number from storage and make it available to the arithmetic section.
Accumulator or Counter	A device which is capable of addition and subtraction. This is usually found in the arithmetic section.
Address	A symbol, numerical or alphabetic, designating the storage location of one number or word.
Analogue Computer	A computer in which numbers are represented by physical magnitudes, such as the amount of rotation of a shaft or a quantity of electrical voltage or current (see digital computer). Nomographs or charts which represent quantities of lengths of lines on a sheet of paper are of the analogue type.
Arithmetic Operations	Addition, subtraction, multiplication, and division.

Arithmetic Unit	That part of the machine in which the arithmetic operations are performed.
Binary Coded Decimal	A system of representing decimal numbers in which each decimal digit is represented by a combination of four binary digits. For example, the IBM Type 604 Electronic Calculator uses this type of representation.
Binary Digit, Bit	General name for either of the symbols in the binary system.
Binary Number System	A number system using the base two. There are only two symbols: one or zero ("on" or "off"). Digit values reading from *right* to *left* are: 1, 2, 4, 8, 16, 32, etc.
Bucket	A slang expression for that part of a storage device which stores one number or word of information.
Cathode Ray Tube (electrostatic storage tube)	An electronic tube, something like a television picture tube, used for storing information in some machines.
Control	The section of a data processing machine which controls all operations of the machine. It may be compared with a fully automatic telephone exchange.
Data Processing Machines	A general name for machines which can store and process numerical and alphabetic information (see analogue and digital computer).
Decimal Number System	The common number system using the base *ten* and having ten symbols which are: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9. Column unit values reading from *right* to *left* are: 1, 10, 100, 1000, etc.
Decimal Bit	any weight 0, 1, ..., 9
Channel...	common line or bus

Digital Computer	A computer to process data consisting of clearly defined numbers as opposed to physical quantities processed in an analogue computer (see analogue computer).
Diode, Crystal Diode, Crystal Rectifier, Germanium Diode	An electric element used in computing machine construction which will pass current in one direction only. Similar in operation to "filters" found on standard IBM Accounting Machine control panels.
Erase	To destroy the information stored on the surface of a magnetic tape, magnetic drum, or cathode ray tube in order to make this storage space available for storage of new information.
Input	Information (instructions or data) delivered to the machine.
Instruction	An order to the machine to perform some operation. The instruction usually contains also the storage address of one or more numbers which are to be used in the operation.
Magnetic Drum	A rotating cylinder surfaced with a material which can be magnetized. This is used to store information. Information is stored by the presence or absence of magnetized spots on the drum surface.
Magnetic Tape	A flat ribbon of metal, plastic, or paper which is coated on one side with a material which can be magnetized. Information is stored on the tape by a combination of magnetized spots in certain patterns.
Microsecond	one-millionth of a second.
Millisecond	one-thousandth of a second.
Output	Information produced by a machine.
Output Device	Part of a machine which translates the intangible electrical impulses processed

by the machine into tangible permanent results:

1. Printed forms
2. Punched cards or tapes
3. Magnetic "writing" on magnetic tape.

Parallel Operation — The type of operation within the arithmetic section of a machine so that all digits of a number are handled simultaneously. For example, the usual desk adding machine has a parallel type of operation.

Permanent Storage — The medium used to retain intermediate or final results outside of the machine (see output device). This is usually in the form of punched cards, punched paper tape, or magnetic tape.

Printer, Line Printer, Single Stroke Printer — Unit of the machine which prints the results obtained from processing some data. Numbers, letters, or symbols may be printed, depending on the device. A line printer records one line of symbols simultaneously, as, for example, an IBM Type 402 or 407 Accounting Machine. A single-stroke printer records one symbol at a time, as, for example, an IBM Electric Typewriter.

Read, Read In, Read Out — The operation of transferring information from one type or location to another type or location. For example, punched cards or magnetic tapes may be read and the information they contain may be transferred to other storage locations within a machine.

Serial Operation — The type of operation within the arithmetic section of a machine so that a number is handled one digit at a time (see parallel operation).

Sign, Sign Digit — The symbol or symbols which distinguish positive (+) numbers from negative (−) numbers for a machine.

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