Electronic Information-Logic Machines

By L. I. Gutenmakher

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TRANSLATED FROM THE RUSSIAN BY ROSALIND KENT

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Preface

The ever-growing volume of recorded knowledge, often characterized as the "knowledge explosion," has stimulated considerable research attention throughout the world. After having followed the Soviet work in this field for a number of years, I spent four weeks in 1958 and one week in 1959 in Moscow engaging in detailed discussions with a number of Soviet scientists who were doing interesting work in the field of information storage and retrieval. These visits were followed by continuing contacts in the United States and at various conferences in other countries.

My wife, Rosalind Kent, who did not accompany me on my trips to the U.S.S.R., was determined to act as interpreter on my next trip, and accordingly started intensive study of the Russian language—from scratch. When the book by L. I. Gutenmakher *Electronic Information-Logic Machines* was sent to me my wife undertook its translation, with the pages following being the result.

Many readers will find much that is familiar on these pages, but I trust that almost none will ever have read the relatively thorough and detailed presentation of the thinking of one Russian scientist who, as Director of the Laboratory for Electromodelling, has a challenging and important assignment in the information-retrieval field.

The question of the state of the art of the U.S.S.R. in the information-retrieval systems and hardware field has been the subject of uninformed and often emotional argument. Many of the experts who have visited the U.S.S.R. and have had little opportunity to study Russian developments more than superficially have returned to present opinions to their colleagues in the United States. These opinions have varied violently, and have tended more to confuse than to enlighten.

The present translation, therefore, is presented to the workers in the information-retrieval and computer field with almost no editorial comment, in order that opinions and evaluations may be made personally and that future discussants come armed with facts as well as emotions.

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Preface to the Russian Edition

This book discusses memory devices, various aspects of automatic "memories," which are a part of every electronic machine, and the basic principles of their operation. Most space is allotted to describing the methods by which ordinary information is transformed into "machine language"—ciphering by means of specialized codes. Also the automatic input of information into machine memory is discussed, that is, the independent reading of books by machine without human intervention. We will also examine the various aspects of information machines with large memories and their application to the various fields of science and technology.

ACADEMICIAN A. A. DORODNITZIN

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Fundamental Concepts

I. MACHINE CHARACTERISTICS

Until recently, the concept of machines referred to devices that (*1*) transfer one form of energy to another form which is convenient for exploitation (*motors*: steam engines, gas turbines); and (*2*) aid in creating a change of form, property, condition and position of materials (tools: metal working, textile, transport). Mechanization was considered a means of fully or partially replacing muscular, manual labor of people or animals by machines. No wonder *horsepower* is used as a unit of measuring the force of machines.

At first, machines could be used only to replace directly the manual labor of many people. However, as new machine functions were created and were developed rapidly a rapid qualitative change took place. Machines came to conduct complex and difficult physical work which was impracticable for people and animals. For instance, consider the impossibility of using people or animals to create the power necessary for the flight of an airplane. It is impossible to provide the high speed of execution of many intricate industrial processes necessary in different fields of the national economy by manual labor.

With the development of science and with the increase of accumulations of knowledge by mankind, the necessity arose for the mechanization of intellectual work. The concept of machines for use in this connection has already been broadened to include the category of new devices which are intended for executing certain processes of human intellectual labor.

In certain aspects of intellectual labor memory is utilized for retaining information obtained by man as a result of his development and personal contact with the external world. In the narrow sense of the word, all knowledge entering the memory from the outside world may be called information. Information represents the raw material of the thinking process, and mental activity of man is based on the processing of information.

Thinking is a specific property of the human brain. The forms and laws which relate thoughts to reasoning are studied by a special science—logic—, and the operations of processing information by the human brain in this sense may be called logical. Processing of information and obtaining a deduction consists of the operations of comparison, analysis, and synthesis, i.e., of a series of logical actions upon concepts and judgments.

In examining the problems of mechanization of certain processes of intellectual labor, we limited the concept of information to only those data (ideas and concepts) which can be made explicit by written language (for example, printed publications, manuscripts, graphic material, tables). Mechanization of certain processes of intellectual labor involves the perception, storage, and manipulation of such forms of information by machine, based on a logical program of action formulated by man. Machines designed for this purpose are called information-logic machines. The volume of information accumulated and processed by such machines must be commensurate with the volume of information digested by the human brain, which performs the intellectual labor subject to mechanization. This point makes clear the *first*, qualitative, difference between information-logic machines and any other machines.

The information-logic machines process a certain form of "raw material," as do other machines. As already mentioned, this raw material is information which is expressed in written language. The raw materials processed by conventional machine tools are converted into the manufactured product, and in order to produce more of the new product, more raw material is needed. However, in the information-logic machines the raw material is not consumed and the wealth of information is not exhausted. This is the *second*, qualitative, difference between the information-logic machines and other machines.

The information stored in the machine, e.g., a million words in volume, can be used for the production of an almost infinite amount of diverse information. On the whole, the stored information does not become obsolete and the "memory" of the machine is generally enriched by new knowledge, which enters from new sources or is formed as a result of the logical operation of the machine itself. The production of these machines is now becoming possible thanks to the high level of development of electronics. The modern facilities of electronics permits the construction of a high speed machine memory for storage and reproduction of a greater volume of information, and also the high speed logical elements and circuits for the processing of this information. Using established principles, an electrical stationary (static) memory was constructed—one not having mechanical movement and based on the utilization of magnetic flux and other properties of electrical systems. These memory devices are able to store information for a practically unlimited period of time and reproduce it at a very high speed (10,000 bits of information per second). Besides, the long-term memory devices can be "addressed," that is, necessary information is selected from the memory independently according to given addresses without scanning everything stored in the memory. In contrast, memory devices such as magnetic or perforated tape basically cannot be used for the construction of the information-logic machines with the qualities indicated since tape devices require a longer period of selection (considerably more than human). The time for selection of information from only one reel of magnetic tape is more than a minute. For the selection of information having a given characteristic, it is necessary to scan either the entire volume of stored information (a large quantity of reels) or a part of the reels. As a result of mechanical transfer, the tape wears away and the information which was recorded on it disintegrates. Therefore, a machine memory which involves the use of some sort of mechanical transfer does not possess the qualities of durability, preservation, and permanence of storage of information which are required for the core memory of the information-logic machines. Therefore, magnetic tape, perforated tape, and other forms of memory devices with mechanical transfer will be used in the information-logic machines as external devices, and also for the input and output of information. The relationship between the external meomry and the internal memory of the machines will be similar to that between a library and human memory. (It is necessary, however, to point out that operations prior to the construction of a very large internal machine memory are conducted with magnetic discs, drums, and tapes.) Thus, the *third*, quantitative, difference of the information-logic machine is the durability and permanence of the information which has been introduced into the machine memory. The reproduction of stored information in a permanent form must provide for many years' stability.

The processes of mechanized intellectual labor, of course, should be compared with similar processes of human intellectual labor, just as machine tools and engines are evaluated in terms of the manual labor replaceable by them. Algorithms,* the apparatus of mathematical logic and theory, are used in the information-logic machines. The rules, conditions and program of the machine's performance of one or another intellectual operation are determined on the basis of these algorithms. Man quickly responds to certain external information, expressed by words. It takes man from one to several seconds to select from memory the necessary information and data which accompany it (associations), but the logical processing of information (comparison, analysis and synthesis) is extended over a rather long time. The potentialities of the human brain are immeasurably greater than those of modern, operational information-logic machines with regard to flexibility, self-organization, adaptability to diverse, continuously varying conditions, and with regard to the logical methods at its command. However, if some particular intellectual labor can be formalized and algorithms can be composed for it, then the processes of selection and processing of information by given logical methods can take place in the machine at a rapid rate which exceeds significantly the rate of selection and processing of information by the human brain. The speed of the machine reaction to a given question will be commensurate with, or greater than, the speed of execution by man of the mental labor under consideration. This, then, is the *fourth*, quantitative, difference of the information-logic machines.

II. SPECIALIZATION AND "QUALIFICATIONS" OF THE INFORMATION-LOGIC MACHINES

Information-logic machines may be used, for example, for the following purposes:

1) The processing of results of scientific investigations and engineering operations (technological, schematic, design of instruments and machines). The basic raw materials for this processing are articles, books, experimental data.

2) The automation of the processes of searching the information in the world's stockpile of literature. The total number of printed works accumulated by man consists of nearly 100,000,000 titles. Naturally, the search for information in such a quantity of literature sources is extremely troublesome, and without new types of

* An algorithm is a program for automatic operations (a set of different operations, effects, or sets for obtaining a given product, or a precise rule for performance of operations in established order during the solution of a particular type of problem).

machines a person cannot, in practice, use all the material which is available with respect to each given problem.

3) The processing of statistical information that is accumulated in industry, agriculture, and in transportation. The raw materials for this processing are abstracts, tables, graphs, etc.

4) The processing of case histories observed for patients in clinics, hospitals, and dispensaries. The information can be recorded in the machine's memory and logically processed for study and prevention of epidemics or for deriving general conclusions from disease symptoms.

5) The processing of accumulations of observations of natural phenomena. Data which are conveyed by meteorological and seismological stations, observatories, earth satellites, and automatic transmitters of cosmic rockets are subjected to a system of processing.

It is quite obvious that the volume of human memory cannot hold all the information that must be subjected to reprocessing in the cases cited. It is sufficient to say that at present in the U.S.S.R. there are more than 3000 meteorological stations, at each one of which there are carried out daily 8 observations for 15 criteria. The total quantity of information coming from the meteorological stations into the central archives consists of several tens of thousands of reports per day. For weather forecasting, for example, it is necessary to reprocess not only this information, but also that which was obtained earlier and which is stored in the archives. Therefore, the speed of processing must be great.

By the precise reproduction of accumulated information, the machine can perform work that generally cannot be performed in a practical manner by people.

It is possible to elucidate the special-purpose nature of the information-logic machines by discussing the functions they can perform. During mechanization of physical labor, machines execute certain specialized human functions (e.g., of a smelter, of a blacksmith, of an excavator). In an analogous manner, the information-logic machine executes certain functions of the human who performs specialized intellectual labor (e.g., librarians, scientific workers, engineers, physicians, planners).

Analogous to determining the qualifications of workers of intellectual or manual labor, the "qualification" of the machine may be determined by evaluating it in terms of the quality of products manufactured, in terms of the quantity of various types of operations which it performs, and in terms of its efficiency. Since the human memory stores a volume of information and performs logical associations during intellectual labor, then the "qualification" and performance of the information-logic machine must be evaluated in terms of the volume of the machine memory, its logical possibilities (with respect to complexity of programs it can follow), and by the speed of processing of information.

The rating or "qualification" of the information-logic machine depends not only on the quantity and quality of the information which is stored in it, but also on the quality of its program. The program is written by a human (programmer) and establishes a series of logical activities (operations), which are to act on input information. The machine fulfills this program of activity automatically and also can transfer from one program to another. Furthermore, the information-logic machine can itself automatically write new programs for the solution of various problems, based on what is available in its program.

The material on record in the memory of the machine, first of all, is reduced to a form convenient for this record. For example, any grammatical sentence form that is arbitrarily found in original book text can be converted to a standard form of record (standard sentences) by following specific established rules. The words and symbols of the text are converted into discrete coded symbols. Other forms of original information are also subjected to the same processing as was previously mentioned.

The program of operations is also coded by similar means. The code represents a series of symbols, or sets of combinations of symbols, compiled from the various alpha-numeric characters available. For example, in binary notation only two characters are used—1 and 0. This system of calculation is the most convenient for the recording and processing of information in electrical devices, since the code elements reflect one of two possible stable positions ("yes–no," "switched on–switched off"). Therefore, the volume of information is usually estimated by the quantity of recorded binary digits.

The speed of the information-logic machines is determined, first of all, by the speed of selection of information from the internal memories and by the speed of comparison of this information with the given features. The speed of selection depends to a large extent on the organization of the address system of the machine memory. In ordinary electronic calculating machines the numerical address allows the selection of information only by a given number of the memory unit, but in the information-logic machines the selection of information is accomplished not only by a given number, but also directly by a given word (word address system) or by a given association or combination of ideas (associative address system). This more ideal organization of the machine memory is the basic distinguishing feature of the information-logic machines.

The speed of execution of the logical and arithmetic operations in the machine also is of great importance. The information-logic machine performs its work by communicating with external devices from which it obtains information and questions and into which it sends answers and decisions for problems. Information may be inputted by various means:

1) *Seeing machines:* direct "reading" by an electronic-optical device
2) *Feeling machines:* using perforations on cards or tape, or of magnetic records on tapes, discs, or drums
3) *Hearing machines:* converting sound vibrations of speech into input electrical signals.

The output of the information-logic machine must also be expressed in written language in order to profit man. Therefore, the results of the machine's efforts must be read out with the aid of specialized output devices. The information in the machine output can be expressed in the form of printed statements (tables, documents), images of this information on screens of television receivers, or sound reproductions of this information (speech).

III. BLOCK DIAGRAM OF THE ELECTRONIC INFORMATION-LOGIC MACHINE

The working principle of the information-logic machine is represented in Figure 1. The information from the various external sources of information enters the machine through the input and coding device.

Sources of this information include hand keyboard, punched cards, perforated tapes, microcards, microfilm, magnetic tapes, and photoelectric scanning devices (accomplishing immediate reading of the printed texts from books, journals, films and microcards).

In the coding device the information is converted into a binary code, and subsequently, by means of a system of recording and

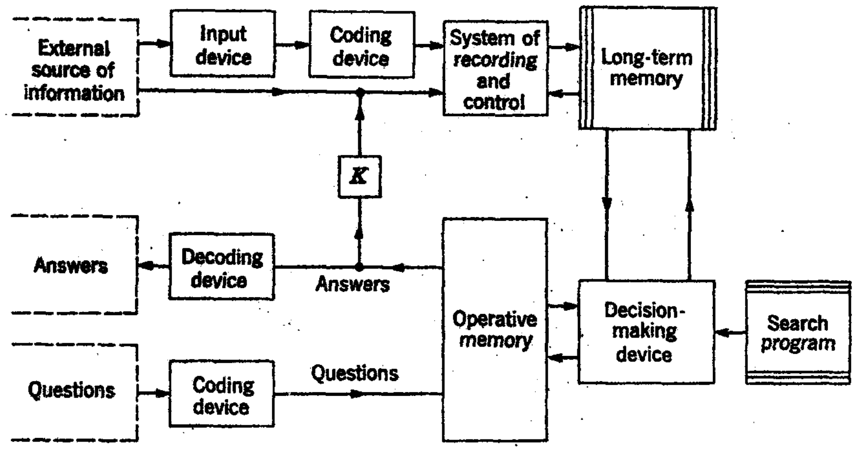

Figure 1. Block diagram of the information-logic machine.

control, electrical signals enter the long-term (permanent) memory device. The long term memory device is composed of a row of blocks ("books") in which there is continually accumulated all the information entering the machine. These blocks are incorporated with the general address system of selection of information and comprise the permanent memory—the "library" of the machine. Obsolete or unnecessary information can easily be extracted from the "library" and replaced using a new method which involves the automatic electrical "detaching" of a section of "pages" from books and adding new ones in their place.

The machine memory can be enlarged gradually. The more original the data accumulated in the machine, the more valuable they are. The special internal link K (Figure 1) permits valuable answers obtained as results of searches to be introduced into the permanent memory just like new data.

The question and search programs in coded form are inputted into the operative memory device, in which the device registers and temporarily stores all the operative information (questions, intermediate results of the logical processing of information, answers) by electrical means. The operative information is stored only at the time a given problem is being solved. Upon completion of this problem this information is erased by electrical means so that the operative memory is prepared to accept new information.

The standard programs for obtaining answers to questions are recorded in separate blocks of the long-term memory which are not a part of the main library, but which are connected to the decision-making device of the machine. The search programs can be added to the program library, thus enlarging the range of problems that can be solved and permitting the programs for some new problems to be compiled automatically from programs already stored in the machine.

The use of the high speed, long-term memory for the storage of search programs gradually increases the "qualifications" of the machine and leads to increasing flexibility in handling problems. This is the essential qualitative difference of machines with a greater long-term memory.

This computing device is also connected with the long-term and operative memory of the machine. In it are units for reproduction of information and also comparator, logic, and arithmetic units. The answers to given questions and problems are stored in the operative memory. Subsequently they are converted into the usual form of printed text in the decoding device and are discharged by the output device in the form of references.

IV. THE MACHINE MEMORY AND HUMAN MEMORY

For the operation and construction of information-logic machines it is necessary to analyze the processes connected with the corresponding thinking processes of man. What, however, is known to us about the work of the human brain? The ancient Greek physician Hippocrates began using the scientific method to study the human brain. He wrote that only from the brain do our feelings of joy and grief originate, that owing only to the brain do we see and hear, distinguish the ugly from the beautiful.*

A. The Brain—An Organ of Higher Nervous Activity

The brain, in its cortex, has a conglomeration of microscopically small elements—neurons (gray matter). The brain contains 10 to 15 billion neurons, each one approximately 1 mm in length and 0.01 mm^2 in area at the base. The neurons (elementary cells) are connected in a common network with the aid of "conductors" of neurites and dendrites. The volume of the brain is approximately 1.5 cubic decimeters, the weight approximately 1.2 kg., and the electrical output approximately 2.5 v.

Research (using the electroencephalogram) has shown that the

* Penfield, Wilder, *Proc. Natl. Acad. Sci., U. S.*, **44**, No. 2 (1958).

action of neurons is conveyed in the form of electrical activity—in the change of electrical potentials. The potential of the neuron in relation to the outer membrane is approximately 0.1 v.

Each section of the brain cortex performs a specific thought function (that is, the functions of the separate parts are strictly localized). However, together with this assumption are hypotheses negating such strict localization. As an example in favor of the assumption concerning localization of the functions of the separate sections of the brain there are the results of the following experiments.

During a brain operation performed under local anesthesia, a specific section of the right half of the cortex was stimulated by an electrical current by use of an electrode. The patient said that he heard music. Each time the electrode was inserted or very quickly removed the patient heard orchestral music. The patient was asked to reproduce the melody, but couldn't without stimulation by the electrical current.

With another patient, stimulation of a specific point of the brain induced the recollection of a book which she had read. When the stimulation occurred only a single centimeter away from that point, laughter was induced in her—she recalled some happy story.

It is possible to conclude that the brain registers everything which man encounters in life.

The experiences which a person undergoes during irritation of specific points of the brain are not merely recollections. They are rich in minute details which are impossible to remember even by mental effort, and which are so clear that the subjects could become frightened, or be happy, even though they knew full well that they were lying on an operating table. Nevertheless, in the psychic life of man many such things occur which perhaps can never be caused by responses to electrical stimuli. Creative thinking may not be induced as a psychic response.

The connection of the brain cortex with the organism and the outer world occurs by means of cells below the surface through which stimuli enter from the sensory organs. In turn, stimuli in the brain cortex are transmitted from one layer to another (there are 6 layers in all), from one place to another, and thereby some parts of the cortex are found in the stage of stimulation, others in the stage of inhibition. During the process of intellectual labor a mosaic of stimulated and inhibited cells (groups of neurons) are generated