Central Intelligence Agency

Washington, D.C. 20505

5 April 2018

Mr. John Greenewald, Jr.
27305 W. Live Oak Road
Suite #1203
Castaic, CA 91384

Reference: F-2017-00295

Dear Mr. Greenewald:

This is a final response to your 17 November 2016 Freedom of Information Act (FOIA) request for copies of three documents entitled:

1. **Directory of Officials of Vietnam;**
2. **World Press Treatment of the Use of Gas in Vietnam; and**
3. **Artificial Intelligence Research in the USSR.**

We processed your request in accordance with the FOIA, 5 U.S.C. § 552, as amended, and the CIA Information Act, 50 U.S.C. § 3141, as amended.

We completed a thorough search for the documents responsive to your request and located one document, consisting of 67 pages, responsive to Item 3. We determined that the information can be released in segregable form with deletions made on the basis of FOIA exemptions (b)(3) and (b)(6). A copy of the document and an explanation of exemptions are enclosed. Exemption (b)(3) pertains to information exempt from disclosure by statute. The relevant statutes are Section 6 of the Central Intelligence Agency Act of 1949, as amended, and Section 102A(i)(l) of the National Security Act of 1947, as amended.

With respect to Items 1- 2, we were unable to locate the documents responsive to your request. Although our searches were reasonably calculated to uncover all relevant documents, and it is highly unlikely that repeating those searches would change the result, you nevertheless have the legal right to appeal the finding of no records responsive to your request.

As the CIA Information and Privacy Coordinator, I am the CIA official responsible for this determination. You have the right to appeal this response to the Agency Release Panel, in my care, within 90 days from the date of this letter. Please include the basis of your appeal.

If you have any questions regarding our response, you may contact us at:

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Washington, DC 20505
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Contacting the CIA's FOIA Public Liaison or OGIS does not affect your right to pursue an administrative appeal.

Sincerely,

Allison Fong
Information and Privacy Coordinator

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ARTIFICIAL-INTELLIGENCE RESEARCH IN THE USSR

PREFACE

Artificial-intelligence is a popular term that was coined in the United States during the 1950's to categorize research studies aimed at simulation of intelligent or "thinking" behavior. This type of research seeks to analyze the factors involved in the making, by humans, of specific types of decisions, to specify and define these factors as decision procedures or mathematical algorithms, and ultimately to fabricate hardware which can concretely model decision procedures and thereby assist human decision makers in making increasingly complex decisions. Although current digital computers can assist in the solving of some complex decision problems, artificial-intelligence research has already discovered decision routines which, while they can be modeled on a digital computer for demonstration purposes, are more efficiently solved with other types of hardware. In the future this will increasingly involve some sort of analog or combined analog-digital equipment, possibly a replica of the structure of the human brain, more likely a model abstracting essential elements of brain function on principles not yet uncovered.

Artificial-intelligence research is necessarily interdisciplinary in nature, involving such traditional areas as biology, physiology, psychology and electrical and systems engineering, with a strong under-laying of mathematics. As used in US literature, the term "artificial intelligence" may appear to be a rather flexible "tent," encompassing more or less whatever one desires to place within it. Nevertheless, artificial-intelligence is a "far out" field of scientific endeavor, the surface of which has been merely scratched. Its potential for future accomplishments can be only dimly seen and not evaluated at present. If it succeeds in significantly optimizing decision making in such complex areas as the economy or national strategic planning, it will obviously make a strong contribution to a relatively monolithic system, such as the Soviet one.

In the USSR, research on approaches to the fabrication of problem-solving or decision-making machines (that is, artificial-intelligence research) is conducted under the general category of cybernetics. This report covers Soviet research on major problems in this field, including pattern recognition by machines, machine learning, planning and induction in the problem-solving machine, and brain modeling. It does not cover conventional digital computer solution of problems or on-line computer control of processes.

The material in this report is based chiefly on information from the Soviet open literature available as of 1 May 1964. Additional information obtained through 1 July 1964 does not materially affect the conclusions.

Soviet ideologists and scientists are discussing, from a wide range of viewpoints, the fundamental philosophical problems about the nature of intelligence and of man which are raised by attempts to model decision-making or intelligent behavior. The strictures of dialectical materialist dogma are not inhibiting research in this area. In view of the high prestige of the Soviet scientists taking part in these discussions and the publication in the Soviet scientific literature of the opinions expressed, artificial-intelligence studies represent rare and significant examples of intellectual freedom in the USSR.

Current Soviet work in the major subfields of artificial-intelligence research includes investigation of techniques for machine search of problem solutions, pattern recognition, machine learning, planning and induction in machine systems, and brain modeling. Soviet progress in research on machine techniques for search, pattern recognition, and learning compares favorably with US advances. Scientists and engineers engaged in research on pattern-recognition in the Soviet Union have made original contributions to the theoretical basis for artificial pattern-recognition systems and have fabricated various types of pattern-recognition devices.

Soviet research on simulation of such aspects of the cognitive process as learning and induction at present consists mainly of study of self-teaching and self-organizing systems. In these fields Soviet scientists and engineers have created models based on neuro-physiological conditioned-reflex approaches, on psychological learning theory, and on automatic control system theory.

Soviet study of the exceedingly complex problems involved in incorporating techniques of planning and induction in artificial problem-solvers is at a very early stage of development. As yet, little progress has been made in these fields in the West.

Research on the modeling of brain processes is receiving much emphasis in the USSR. Since 1955, laboratory experimentation on models that simulate neural processes has increased, and outstanding neuro-physiologists and psychologists have begun to work closely with mathematicians, computer specialists, and electronics engineers on cybernetic studies of brain-modeling problems.

Seminars are regularly offered to expose students to the state of the art in the fields that are especially significant to the future of artificial-intelligence research in the USSR. These seminars are conducted by the leading researchers in artificial-intelligence and are thereby laying a sound foundation for future advances in a new and multidisciplinary field.

DISCUSSION

INTRODUCTION

Since the mid-1950's, the Soviet government has increasingly emphasized the importance of a cybernetics research program for achieving national and international goals.* A large part of the theoretical research aspect of this program has been focused on the development of decision-making machines. Realization of such machines would assist the Soviets in solving two types of fundamental problems: (i) decision making on the basis of incomplete data (sometimes referred to as decision making under conditions of uncertainty), and (ii) decision making in the presence of complete but overwhelming quantities of data. Problems of the latter type are by definition beyond the capabilities of human decision makers. Problems of the first type, while inherently characteristic of human thinking activity, are rapidly extending beyond the bounds of possible human solution in the context of economic management and state administration.

*AEC, 828/46, "The Meaning of Cybernetics in the USSR," *Cybernetics in the USSR*, 30 Mar 64, [redacted]

(b)(3)

Decision-making machines are, in essence, models of one variety or another of the human problem-solving process. Models of the human thinking or problem-solving process are artificial simulations of the information flow, or information processing, procedures of the human problem solver. The model may be mathematical, in which case it may be a program for a universal (digital) computing machine, or it may be a piece of hardware, such as an electronic circuitry analog. (Many decision procedures already elaborated by artificial-intelligence research are not efficiently modeled by the single-track, sequential method of operation of conventional digital computers. This would not be surprising in view of the apparent parallel operation of information processing in the human brain. Such decision routines can be modeled for demonstration purposes on a digital computer, but analog models of some sort will loom increasingly important in the fabrication of artificial-decision makers.) In any case, the essential feature of such a model is that for a given input of information the model shall produce at least the same output (of information) as does the natural process being modeled. Research on such models is categorized in the United States under the rubric "artificial-intelligence."

Soviet research on artificial-intelligence has mushroomed since 1956 along with other subproblems of cybernetics. After the establishment in 1959 of a national program for cybernetics, the direction of Soviet research on artificial-intelligence became one of the responsibilities of the Scientific Problem Council on Cybernetics of the Presidium, Academy of Sciences, USSR. The Cybernetic Machines Section of the Council appears to be the unit which assigns, monitors, and integrates most of this research work on a national scale. Actual research is conducted at the laboratories and institutes listed in the appendix. The number of facilities engaged in this research can be expected to grow as the cybernetic approach continues to permeate other areas of Soviet science and technology applicable to communication and control problems arising in production industries, the economy, law, government administration, and military activities.

Although much of the application-oriented cybernetics research is at present directed toward the realization of more sophisticated conventional systems for automatic control of machines, plants, space research vehicles, or even economic units, a large part of the theoretical research is related, directly or indirectly, to the development of "thinking machines," or "thinking cybernatons," as Soviet scientists often refer to them. Realization of such machines will have immediate relevance to information abstracting and retrieval, machine translation, and general problem solving, and eventual application to later-generation automatic control systems.

A. A. Lyapunov, a leading Soviet mathematician and editor of *Problems of Cybernetics*, has described the relationship of artificial-intelligence to general cybernetics and the nature of future control systems. He suggests that algorithmization (mathematical modeling) of thinking processes and of control processes is one of the most important aspects of cybernetic theory.[1] Other members of the Scientific Council on Cybernetics, in explaining the importance of artificial-intelligence, state that "the basic products of radioelectronics are various devices for automatic regulation, monitoring, control, and communications. The brain, which fulfills these functions in the living organism, works much more reliably and productively than any present-day radioelectronic machine. . . . Some first steps have already been taken in the direction of constructing practical automata analogous to the brain."[2]

PHILOSOPHICAL ASPECTS

Reexamination of basic philosophical attitudes toward the nature of the brain, of mind, and of man himself is taking place wherever artificial-intelligence research is being conducted. The Soviet Union is no exception. Philosophical-theoretical questions bearing on the simulation of intelligence, or intelligent behavior, are being thoroughly aired and in-

vestigated in Soviet scientific circles, outside as well as within the context of the fundamentals of dialectical materialism.[2-8]

A highly significant discussion took place during June 1962 at a conference in Moscow on "The Philosophical Problems of Cybernetics." This meeting was co-sponsored by the Scientific Council on the Complex Problem "Philosophical Questions of Natural Science," the Scientific Council on Cybernetics, and the Party Committee, all of the Presidium of the Academy of Sciences, USSR. It was attended by about 1,000 specialists, including mathematicians, philosophers, physicists, engineers, biologists, medical scientists, linguists, psychologists, and economists, from many cities of the USSR.[3] Participants included such prominent cyberneticians* as A. N. Kolmogorov, V. M. Glushkov, A. I. Berg, P. K. Anokhin, A. V. Napalkov, A. A. Feldbaum, A. A. Lyapunov, S. V. Yablonskiy, I. B. Novik, and Yu. Ya. Bazilevskiy. Of the 10 reports presented, six were closely related to the problem of artificial-intelligence.[4] A report of this conference stated that "the problem most animatedly discussed was the most disturbing of all, the problem of the technological operation of complicated psychic processes—the problem most frequently designated by the short and convenient although not, in our view, entirely correct formula of 'can a machine think?'"[5]

The discussion brought out three questions as approaches to this problem. First, Is it possible in general to reproduce with models the complex intellectual activity of man? Second, Can a machine surpass man in the realm of intellectual activity and particularly in the performance of creative tasks, such as the formulation of new problems? Third, Is it possible in principle, to achieve the existence of consciousness in a machine similar to that exhibited by man?

Discussion at the June conference of the first question may be described as informational and confirmatory rather than argumentative. There was general agreement that, in view of the replications of intellectual and sensory functions of man already achieved, an affirmative answer to questions about the reproduction of human cognitive processes cannot be doubted. The second question was discussed more vigorously. Life scientists, represented by P. K. Anokhin, a leading neurophysiologist, argued that the potentialities of a machine are limited to solving problems assigned by man using algorithms of decision which man puts into the machine. This position was countered by V. M. Glushkov, a leading Ukrainian cybernetician, and A. A. Feldbaum, Doctor of Technical Science in Electronics and member of the automation faculty of the Lenin Power Institute. They pointed out that there are machines today which, in the process of solving one complicated problem, can independently pose and solve a series of autonomous problems of a particular character. Glushkov maintained that any form of human thought can, in an informational model, be reproduced in artificially created cybernetic systems. He agreed, however, that by virtue of historical necessity—the fact that it was precisely man who created machines for his use and not the reverse—the destiny of man will always be the more important in the processes of thought and cognition. Thus Glushkov's assessment is that a machine can be "smarter" than one man, or even a group, but it cannot be "smarter" than human society as a whole.

Questions about machine consciousness were argued most sharply at the conference. One group argued the "black box" approach to solution of these questions. This viewpoint holds that man judges the presence of consciousness in other people by analogy, i.e., by observing the behavior manifested by others in response to inputs (stimuli) and by comparing such manifestations with his own behavioral responses of which he is consciously aware. Therefore, if a machine faithfully produces the same outputs as a man in response to the same inputs, it can be analogously inferred to possess consciousness according to this view. On the other side it was

* The term "cybernetician" is applied by the Soviets to those practicioners of traditional disciplines who exhibit the common characteristic of dealing with their research problems in the framework and methodology of cybernetics.

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maintained by some at the conference that consciousness necessarily includes a subjective element with a specific character which is the result of the labor and social relations in which people engaged during the process of social evolution.

A more empirical approach to consciousness was advanced at the conference by those scientists interested in modeling the structure which embodies human consciousness, that is, the brain. Although a structural model of the human brain is far beyond present technological and scientific capabilities, the possibility of its future realization is considered to be worth discussion by the Soviets. A. N. Kolmogorov, world renowned mathematician, is optimistic about the chances of success in brain-modeling ventures. He called for the freeing of definitions of life and thought from arbitrary premises and for the redefinition of these concepts along purely functional lines. Kolmogorov believes that if the functional point of view toward life and thought is subscribed to, the conclusion is inevitable that replication of the organization of a system can be accomplished by organizing different elements into a new system which would have the essential traits and structure of the system being modeled. From this Kolmogorov concluded that:

> A sufficiently complete model of a living being can in all justice be called a living being and the model of a thinking being, a thinking being. It is important distinctly to understand that within the limits of a materialistic ideology there do not exist any kind of well-grounded, principal arguments against a positive answer to [this] question. This positive answer is the contemporary form of the attitude concerning the natural origin of life and the material basis of consciousness.

The extreme empirical view advanced by the Kolmogorov school seems to be in the ascendancy. For example, several points of view on the question, "Can a machine think?" have been reviewed by a group of authors in the *Works of the Kazan Aviation Institute*, a somewhat surprising source for discussions of philosophical aspects of artificial-intelligence.[6] The group did not find convincing any of the arguments against the possibility of creating a thinking machine. The subject of the negative arguments considered by them ran the gamut from the algorithmic insolvability of some problems, and the irreducibility of the thinking process to a physical operation, to the impossibility of modeling the subjective-psychological world of man. The Kazan group points out in rejecting such arguments, that cybernetics provides the first basis for (i) uncovering the elements involved in consciousness and cognition and (ii) "resolving positively the question of the possibility of creating a thinking machine." The Kazan group does not recognize the brain as the only highly organized material system in which consciousness can develop, and forecasts that highly organized material systems of another type, in which consciousness develops, are possible and realizable.

V. M. Glushkov, one of the most politically powerful among Soviet cyberneticists,* sides with Kolmogorov and the Kazan group. Recently, in discussing the possibilities of machine intelligence, he contrasted cybernetic systems with earlier mathematico-logical and other formal language approaches to modeling the thought processes. He found significant advances in the cybernetic approach. Glushkov would describe any control or cognitive system as a cybernetic system which can be analyzed as an abstract [informational] model. For this purpose, both the input and output information, that is, all of the information which a system exchanges with the outside world, can be conceived as being encoded in words of a given standard alphabet. All of the activity of the cybernetic system may thus be reduced to the transformation of words in a standard alphabet. The study of a given cybernetic system can be reduced thusly to the determination of rules according to which the indicated transformation occurs. Glushkov noted that among these rules there may be some which permit certain

*V. M. Glushkov is Vice President of the Academy of Sciences, Ukrainian Soviet Socialist Republic; Director of the Institute of Cybernetics in Kiev; Chairman of the Cybernetics Council of the Ukrainian Academy; and Chairman of the recently created Interdepartmental Council for the Introduction of Mathematical Methods and Electronic Computers in the National Economy, which is under the State Committee for Coordination of Scientific Research of the Council of Ministers, USSR.

chance transformations, as well as some that permit the altering of other rules of information conversion in the course of time under the influence of an infinite surrounding medium. Appreciating the possible infinitude of the system of rules defining the regularities of the informational activity of the brain, Glushkov believes that the modeling of a sufficiently large number of the essential rules in the brain system eventually will result in a behavior pattern of the model (on the informational level) which will correspond to brain activity.[8] Glushkov has asserted that, since modern electronic digital computers possess "algorithmic universality* . . . it is theoretically possible to model [on the informational level] any thought processes with the aid of such machines."[8, p. 10]

At least as significant as the content of these epistomological disputations is their wide distribution in popular and Party media. Typical of "thinking machine" discussions is an article in *Znaniye-Sila* (*Knowledge is Power*, a popular-science type of magazine). It describes the parallel mode of operation of the brain (carrying out several calculations or decision procedures simultaneously) versus the series (single-track) nature of contemporary electronic computing apparatus and points out the advantage of the former in efficiency and universality. It reports that Soviet researchers are studying the operating principles of automata which work in parallel instead of in series.[9]

Soviet research in artificial-intelligence is motivated by the anticipated necessity of using machines in place of people in situations where speed, complexity, or other characteristics of control processes exceed the capability of man. The Soviet policy regarding the use of "thinking machines" was expressed in a recent edition of *Kommunist*. The development of technology, with the increase in speed and accuracy requirements of separate production operations and the growth of the entire technological process as a whole, was said to have begun to exceed, in most cases, man's power to control them. The *Kommunist* article concludes that it is necessary to replace even the psychic activity of man in such cases with automatic control machines.[10]

*That is, computers can perform any information transformation on the basis of a program (algorithm) built out of their available elementary instructions, if these include rules which define chance transformations and instructions by which certain alterations are made in the system of rules.

PRINCIPAL RESEARCH PROBLEMS

The "tent-like" character of artificial-intelligence research has resulted in a somewhat chaotic state in this field of science.[11-13] There are several schools, each represented by spokesmen as critical of other schools as they are competent in the techniques of their own. The result is a lack of standardized criteria for use in assessing Soviet research in the field of artificial-intelligence. Thus, an expert in one popular US approach, upon discovering a lack of comparable work in the USSR, will give a negative evaluation of Soviet research in artificial-intelligence. On the other hand, the opponents of that particular US expert will argue that the absence of such research in the USSR signifies that the Soviets have withdrawn from a blind alley of investigation. Many of these conflicts are semantic; almost all of the approaches to artificial-intelligence share a common set of problems. When Soviet research on these problems is compared with US approaches to the same problems, regardless of "schools," the USSR and the US are found to be approximately on a par.

There are differences in emphases, however, between Soviet and US approaches to these shared problems. US scientists tend to emphasize mathematical or machine models of human cognitive processes. Many Soviet researchers on the other hand consider that the human brain has reached certain limits in regard to its capabilities for memory and operational speed after a long process of slow evolutionary development.[14] The resultant qualities of the human brain, therefore, are not believed by the Soviets to be equal to all the tasks modern men must face. According to them, a machine that might be a perfect analog of the brain, for instance, will not do any better than the brain when faced with

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such tasks. Therefore, if the ever more complex problems are to be solved, machine "brains" surpassing those of men must be built. M. V. Keldysh, President of the Academy of Sciences, USSR, in making this point asserts: "We must copy nature's processes in technology creatively rather than literally, with full knowledge of nature and of technology so that we may select techniques which will give us better results than those achieved in nature."[15] The natural processes to be copied "creatively" in the Soviet research program are the same processes investigated by US scientists of most schools concerned with artificial-intelligence. These are search, pattern recognition, learning, planning, and induction.[16]

Search and Pattern Recognition

The first approach to machine solution of a problem is search. Given a problem, a contemporary data-processing machine in the USSR as elsewhere, can search rapidly by trial and error through a large number of possible solutions for a valid solution to the given problem. Nevertheless, in solving complex non-trivial problems, the number of possible solutions is so large that this trial-and-error methodology becomes excessively time-consuming in practical operation.

Soviet scientists recognize that a large reduction in search time, although bringing some real problems into the realm of practical machine solution, could be achieved by the introduction of pattern-recognition techniques. The machine that is designed with pattern-recognition aids-to-search could classify problems into categories amenable to certain types of solutions. The current state of Soviet and Western research suggests that such techniques are nearing practicability for more and more complex patterns.

Theoretical studies for pattern-recognition devices began in the USSR as early as 1953.[17-20] The philosophical, physical, and psychological bases of perception were extensively discussed in *Voprosy Psikhologii* (Questions of Psychology) in 1959.[21] More recently, Soviet researchers have accomplished considerable work on the specifics of minimum descriptions of images that are required for recognition by artificial systems.[22-27]

The works of E. L. Blokh, mathematician at the Institute for Information Transmission Systems and E. M. Braverman of the Institute of Automation and Telemechanics are notable among recent approaches to practical solutions of recognition problems. Braverman has originated a "compactness hypothesis"* as a theoretical basis for solution of such problems. Several Soviet researchers are using this theory as a basis for development of specific recognition techniques. E. L. Blokh is using certain operations to compute the distance and angle between elements, representing various patterns presented, in an n-dimensional configuration space. This appears to be a promising mathematical modeling approach to a large class of pattern-recognition problems.[29]

Pattern-recognition modeling studies are being supported by research on perception from the psychological and physiological points of view. One investigation involved the establishment and development of perceptual activity in 3- to 6-year-old children. Eye movements of the subjects were observed and recorded photographically as the children examined (for learning) and later recognized pictures presented to them. The eye-movements recorded were then compared with measures of the recognition ability of the children at different ages.[30] Another study was devoted to identification of objects in the visual system. Time required for subjects to recognize simple objects, formed of small numbers of elements, correlated well with an information theory model for such recognition that was based on earlier findings on information collating and processing activity in the eye system.[31]

*The "compactness hypothesis" is formulated as follows: Patterns presented to the artificial system are characterized by a number of criteria equal to n. The values of the n criteria are used to establish points in an n-dimensional configuration space. Each point represents an individual pattern. All points representing patterns which are similar, for example, all letters "A," all figures "5," all pictures of cats, will tend to lie in "compact" regions of the space, with relatively easily discernible separations between regions.[28]

Soviet work in the area of realization of physical models to perform pattern recognition has been reported. At a 1957 Scientific-Technical Conference on Cybernetics, one reading device for an information machine was described.[32] At an All-Union Conference on Machine Translation, held at Moscow State University in May 1958, reports on principles of constructing electronic reading devices were heard, and a device "enabling the blind to read ordinary typographic text" was described.[33 34] (The latter device has been pictured in the Soviet press, but its operating principles were not described in publication.) Hardware modeling of pattern-recognition schemes is being conducted by A. A. Kharkevich, the well-known radio engineer, as well as others.[35-37 61] Some of this research is directed toward the specific application of automating the input of information into computing machines.[38-41]

A quasi-topological method of distinguishing and identifying letters has been developed and realized in hardware by a group of researchers of the Institute for Systems for Transmission of Information (Moscow).[42 43] This makes use of scanning the contour of a letter with a light spot and identifying its topological characteristics (ends of lines, and junctions of lines), which are recorded in a binary code. Since this will not separate all Cyrillic letters, some of which are topologically identical, further geometric analysis is used to analyze topologically redundant groups. Such a scheme is basically sound in theory and relatively easily realized in hardware, but system "noise" (disconnected lines or smudged letters) may be hard to deal with, and no figures have been published on reliability of recognition accomplished.

In June 1960, the Scientific Council on Cybernetics sponsored a seminar on reading devices. This seminar considered the principles of constructing such machines and creating corresponding systems for coding the information involved.[44] Five different machines under development for automatic pattern recognition were described by V. M. Glushkov (letter recognition by line scan and minimal description); V. A. Kovalevskiy (image scanning by following the outlines of letters); A. D. Krisilov (identification of constant features of letters by means of standard television techniques); V. M. Tsirlin (the quasi-topological method) and A. G. Vitushkin (a computer manipulated system for analyzing Cyrillic letters which separates characteristic features by means of vertical line scanning). In addition, E. M. Braverman and V. S. Fayn presented papers on recognition systems employing learning (that is, performing identification on the basis of criteria not given beforehand).

Studies on the mathematical modeling of recognition processes on electronic digital computers have been conducted by M. M. Bongard, an outstanding young biophysicist.[45-47] A report of his in the Cybernetics Council collection *Biologicheskiye Aspekty Kibernetiki—Sbornik Rabot* (Biological Aspects of Cybernetics—Collected Works) describes the methodology and prospects of recently begun research aimed, first, at bridging the gap between physiological study of optical receptor activity and the modeling of recognition, using a universal digital computer.[47] However, Bongard alludes to the disadvantage of this model in contrast to the parallel information processing employed in human recognition activity. He foresees, therefore, the development of a "logic of recognition . . . a logic such that it could be used in an analog computer. In essence, such a machine will be a model of part of the human brain."

Principles for constructing a "universal reading" machine have been developed by V. M. Glushkov.[48] This scheme uses a cathode ray tube-type receptor, a computer to control the trace and to compute the description of the pattern presented, and a technique of comparison against descriptions prestored in the memory for identifying patterns presented. The author admits that the scheme described is unnecessarily cumbersome for the recognition of such simple stylized patterns as digits or letters, but points to its usefulness for "reading" complex contours of

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semitone pictures. Such a "universal reading automaton" has been built at the Computing Center of the Academy of Sciences, Ukrainian SSR, and is used in conjunction with a "Kiev" computer.

A somewhat different "machine that reads" has been developed at the Ukrainian Academy Computer Center under the direction of Candidate of Technical Sciences, V. A. Kovalevskiy.[49 50] This system reportedly failed to recognize only 2 of 35,000 numbers produced with a portable typewriter, including half printed and otherwise distorted samples. In using this method for recognition, according to Kovalevskiy, the maximum of the correlation coefficient for an unknown image and of each of the standard images is sought, the latter images being subjected to all possible transformations. When this is done, all normally typed letters, as well as most of those artificially marred, are correctly recognized and identified, with the statistical error of incorrect recognition not exceeding 10^{-4}.

For solving a more general problem of recognizing nonstandard letters and numbers, an algorithm is being developed which is based on dichotomy, that is, sequential division of the set of all images into two classes. Kovalevskiy believes that such an algorithm will make it possible to work with an alphabet containing many characters and will assure rapid recognition with a comparatively small memory capacity.

Learning, Induction, and Planning

Further improvement in machine problem-solving efficiency could be accomplished with the addition of a learning capability. The machine would then be able to apply readily its already proven methods to the solution of problems that are new but similar to problems previously encountered in the machine's experience. Radical reductions of search time could be realized through the application of planning methods: the machine would survey and analyze the solution space and plan the best way for its detailed examination. Furthermore, to manage broad classes of very complex problems, the machine, as the human, must construct and internalize a model of its environment, that is, it must employ some scheme of induction.

Research on planning and induction in artificial systems is at a rather early stage of development in the USSR, as it is in the West. Progress is occurring, however, in fields contributing to the development of machine learning, induction and planning. Such supporting research includes studies on information theory, coding theory, brain modeling, statistical decision theory, automata theory, and heuristic programming. Pertinent Soviet literature often treats these subjects as conjoined in such studies as pattern recognition employing learning, other learning systems, self-organizing systems, or brain models.

Learning appears to be an essential characteristic of more efficient and truly universal pattern-recognition systems, just as it is of more efficient problem-solving apparata in general. Soviet researchers in the field of learning systems like Braverman, Glushkov, and Mark Ayzerman,* compare favorably with their Western counterparts. Furthermore, they are working on essentially the same types of studies: perceptron-type systems, algorithms for teaching the recognition of shapes, and computer programs for recognition of pattern configurations.[44 51-63]

Investigations of learning systems for recognition are being conducted at a variety of Soviet scientific establishments. At the Institute of Automation and Telemechanics in Moscow, a machine was programmed to discern numerical figures written in different handwritings. According to Soviet reporters, in only a few cases did the machine give erroneous responses, even when confronted with previously unseen figures. The Institute of Surgery of the Academy of Medical Sciences is testing the hypothesis that a "compact area" is formed in the brain of an animal or a human by variants of a similar image. The Institute of Biophysics of the Academy of Sci-

*M. A. Ayzerman is a Doctor of Technical Sciences in mathematics and electronics at the Institute of Automation and Telemechanics, Moscow.

ences is attempting to program a machine that will identify indices of an image and, on the basis of the indices, to recognize the image. In each of the experiments, errors were made by the machine. However, the Soviets believe that the important fact is that the machine is capable of accumulating experience, with the result that its qualifications are increasing and its errors are gradually decreasing.[35]

M. A. Ayzerman's latest experiments involve the teaching of a machine to recognize patterns without a need for pre-introduced criteria. Starting from a basis in Braverman's "compactness hypothesis," Ayzerman develops two algorithms by which a machine can "learn" to distinguish between the compact areas representing different images in a configuration space, thus separating and recognizing the images. The first algorithm has the machine construct, one by one, random hyperplanes whose only criterion is that they separate points which the machine is told (that is, training process) represent different objects. Ending up the training phase with a series of intersecting hyperplanes, the machine then examines these and "washes out" sections of planes which do not perform the separating function, thereby leaving a series of broken hyperplanes which effectively separate areas containing points representing different images. In using the second algorithm, the machine constructs positive potential surfaces (functions) decreasing away from, respectively, each point or set of points representing images of the same object. Identification of a test image (point) is accomplished by (first algorithm) determining on which side of the hyperplanes the point lies, or (second algorithm) determining which potential surface (function) has the highest value at the test point. Tests were conducted with five digits (0, 1, 2, 3, 5), each written 160 different ways. Using 40 samples of each digit for training, and 120 for test, the machine achieved 83–89 percent correct recognition with the first algorithm. With "paralleling" of seven variations of a digit in the training process, 98 percent correct response was achieved. The training sequence filled 1,500–3,000 binary digits in machine memory. The second algorithm was tested using 10 samples of each digit for training and 150 for testing and resulted in 100 percent correct recognizance. Additionally, the second algorithm was tested on the 10 digits from 0 to 9, with 10 samples for training and 140 for test on each digit, and achieved 85 percent correct response.[28 56 57] Ayzerman's second algorithm is very similar to that employed in a US device now becoming operational for the identification of sonar contacts.

Pattern-recognition techniques are employed at the Institute of Surgery imeni Vishnevskii, Moscow, to achieve rapid assessment of the area and seriousness of burns.[64] The algorithm, for recognition of objects with many parameters, employs learning. The system is "trained" on case histories. When vital information, such as burn area and location and patient's age, is fed in, the computer identifies and stores symptoms and other factors. It also identifies objective criteria for forecasting the outcome of the illness. The system was tested on additional case histories with known outcomes, and the prognoses in most cases agreed with the actual course and outcome of the injury.

Many of the Soviet attempts to realize models of learning, induction, and other aspects of the cognitive process are carried on under the classification of self-teaching (or learning) systems, or of self-organizing systems. A significant portion of research in these areas has apparently not been published. In a number of cases the titles of papers discussed at meetings and seminars have been published, but the contents of the papers are unavailable to the West. Thus, a self-teaching machine based on a program model was discussed at the First All-Union Meeting on Computer Mathematics and Computing Technology held in 1959, but details have not been circulated to the West. Other self-teaching machines were alluded to (but only in general terms) at cybernetics seminars at Kiev and Moscow State Universities.[63–67] Since its inception in 1955, the latter seminar, con-

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ducted by the outstanding cyberneticist A. A. Lyapunov, has held biweekly sessions throughout the school year on a wide range of subjects related to cybernetics.

Application of principles from automatic control theory to self-organizing systems study is exemplified by the work of the well-known control engineer and mathematician, A. G. Ivakhnenko. He has surveyed and categorized various types of "learning" and "self-learning" (that is, new information generating) systems and has related US to Soviet work on some of these types. Ivakhnenko is studying the application of the theory of invariance and the principles of combined control systems to the development of certain (self) learning systems. Control principles apply to the memory part of the system, that is, to the control of the selection and accumulation of information in the memory. Ivakhnenko is specifically interested in a perceptron-type device, a scheme first developed in the United States.[68 69] Ivakhnenko's perceptron device apparently employs some variations and innovations in comparison to similar US devices.[70]

Modeling the processes of instruction with automatic systems was discussed in a 1962 collection on automatic regulation and control. Starting from the learning theories of Thorndike, Gestalt psychology and I. P. Pavlov, the authors discussed various machine learning systems. Among the Western and Soviet systems discussed were the perceptron and the approaches of the US scientists Newell, Simon and Shaw, Gelernter and Rochester, and O. Selfridge, the UK scientist, Andrew, and the Special Design Bureau of Moscow Power Engineering Institute. The Soviets view training as a process of changing algorithms, and propose that "a system which finds by means of automatic search an algorithm of action which is successful from any determined point of view and which was not put into the system by man before the training process, should be called a learning system."[71]

Closely related to systems embodying self-learning are those capable of self-organization.* Soviet scientists evinced interest in the theory of self-organizing systems as early as 1959. In that year, S. N. Braynes and A. V. Napalkov wrote on the subject for *Voprosy Filosofii* (Questions of Philosophy). In that study, the investigators related the development of such systems to their work on conditioned-reflex modeling. They foresaw the realization of "an algorithm of operation for self-organizing cybernetic systems, ensuring the formation of new programs for operation without the undertaking of 'exhaustive search' of all possible variants."[73]

Considerable attention was devoted to self-organizing systems at an All-Union Meeting on Computer Mathematics and Computing Technology (1959) and at a symposium on Principles of Design of Self-Learning Systems held in Kiev during 1961. Comparison of the published papers from the latter symposium with those given at the first US Interdisciplinary Conference on Self-Organizing Systems in 1959 reveals very similar topic coverage and a similar level of achievement reflected at the two conclaves. As of 1961, the Soviets were 2 to 3 years behind the United States in this particular area of artificial-intelligence research.[74-78]

Brain Modeling

Historically, there has been a large amount of Russian neurophysiological research since the early 19th century, but its mathematicization is a recent innovation. Brain research now is very much concerned with the algorithmization and modeling of the information transactions which take place in living organisms. These studies play an important role in cybernetics/artificial-intelligence re-

*M. C. Yovits, Chairman of the First and Second Conferences on Self-Organizing Systems, Chicago, 1960 and 1962, considers these areas of artificial-intelligence research to be of great significance. To Yovits it appears that "certain types of problems, mostly those involving inherently non-numerical types of information, can be solved efficiently only with the use of machines exhibiting a high degree of learning or self-organizing capability. Examples of problems of this type include automatic print reading, speech recognition, pattern recognition, automatic language translation, information retrieval, and control of large and complex systems. Efficient solutions to problems of these types will probably require some combination of a fixed stored program computer and a self-organizing machine."[72]

search and are conjoined with attempts to simulate artificially the pattern recognition, learning, planning and induction processes.

Before research could begin in this new field, the whole area of physiology and cybernetics had to be broken out of the restraints of Pavlovian doctrine. The beginning of this break was apparent in a 1955 review of the subject by the well-known Soviet physiologist P. K. Anokhin in *Questions of Philosophy* (*Voprosy Filosofii*).[79] Laboratory experimentation in the modeling of brain processes began shortly thereafter. Some of the earliest work was reported at a Scientific-Technical Conference on Cybernetics, held at the Laboratory of Electromodeling of the Academy of Sciences, USSR, in May 1957. L. I. Gutenmakher, Director of the Laboratory, described work on the electrical modeling of certain mental work processes using "information machines with large internal storage."[80] Research into the structural makeup of the human brain was discussed at the Seminar on Cybernetics at Moscow State University in 1960.[81]

After an artificial-intelligence slant to traditional neuroanatomy and neurophysiology became evident in efforts to model the brain, a new type of interdisciplinary scientist emerged. A. V. Napalkov of the Faculty of Higher Nervous Activity at Moscow State University could well be described as the first of this new breed of physiologist-cyberneticist. In early 1959 he co-authored, with a medical doctor and an engineer, a study which surveys cybernetics and physiology in general, including the theory of automata. Furthermore, these scientists describe the results of studies on brain activity in terms of a search for algorithms representing systems capable of independent development of new programs for their operation, and those able to form new behavior patterns on the basis of processing information accumulated earlier. They also described an artificial device which, in a primitive way, simulates these learning processes, that is, a "learning automaton," and which was developed at the Moscow Power Engineering Institute in cooperation with the life scientists.[82]

More intensive investigations into the information processing procedures of the brain, still in terms of the development of chains of conditioned reflexes, were described by Napalkov in 1960.[83] In 1962, the researchers in the Department of Higher Nervous Activity reported findings which showed increasing sophistication in the greater complexity of the algorithms of information processing that had been derived. By 1962, a much more sophisticated "learning machine," based on the algorithms defined by the neurophysiologists, and exhibiting some capability at "self-organization" (that is, self-improvement), had been fabricated by the engineers at the Power Engineering Institute. This group worked with the neurophysiological laboratory of S. N. Braynes, co-worker and co-author with Napalkov.[84]

Soviet Bloc researchers are also investigating the mode of operation of brain processes from the point of view of psychology. The work of a Czech, E. Golas, on the conditions of generalization in pattern recognition and learning falls into this class of research. His experiments involved a statistical analysis of the process of generalization as manifested by subjects perceiving common elements among sets of stimuli (objects) presented. This study, clearly of a preliminary nature, served only to demonstrate that wide variations characterize the conditions for generalization.[85]

New centers for brain research along cybernetic lines are now being established at the Brain Institute, Institute of Physiology, Institute for Information Transmission Problems and at installations outside the Moscow-Leningrad complex. At Kiev, for example, students are offered the opportunity to obtain training in the most advanced areas of artificial-intelligence research, and specifically brain modeling. In 1962, two seminars were held under the auspices of the Cybernetics Council of the Ukrainian Academy of Sciences. The first, on "Automation of Thinking Processes," was conducted by V. M. Glushkov, chairman of the Council. This seminar covered: (i) the foundations and particularities of thought processes that are characteristic of

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man in the creative sphere of his activity, and the possibilities of their algorithmic description; (ii) modeling on contemporary computers of such processes as pattern recognition, recognition of concepts, identification of meaningful sentences, deduction of logical consequences, proving theorems, selections of strategies in games, and composition of music; (iii) learning as a basis for modeling the mental activity of man; (iv) theory of self-teaching systems and practical development of algorithms incorporating learning; and (v) correlations between precise (to the degree possible) modeling of creative processes and the specifics of machine algorithms simulating these processes.

The second seminar, at the Ukrainian Academy, was led by Doctor of Medical Sciences, N. M. Amosov. Problems associated with biocybernetics and the application of electronics in biology and medicine were considered at this seminar. Specific topics included (i) application of information theory in biology and medicine; (ii) principles of automatic control in biological systems and their peculiarities; (iii) some principles of coding information in the nervous system; (iv) perception and transformation in receptors and the central nervous system; (v) contemporary hypotheses on the nature of nerve excitation from the position of biocybernetics; (vi) some questions of modeling elements of the central nervous system; (vii) thinking and the psychic activity of man; (viii) principles of forming self-organizing neuron nets and bionics; (ix) control of the processes of excitation and inhibition in the central nervous system by means of electrical and electromagnetic influences; and (x) cellular biology in the light of biocybernetics.[46]

APPENDIX

Institutes and Scientists Associated with Research of Artificial-Intelligence Significance in the Soviet Bloc

Academy of Medical Sciences, USSR

Institute of the Brain:

- Glezer, V. D. Retinal activity in identification
- Nevskaya, A. V. (probably). Retinal activity in identification
- Seredinskii, A. V. (probably). Retinal activity in identification
- Tsukkerman, I. I. (probably). Retinal activity in identification

Institute of Surgery imeni Vishnevskii: learning systems for recognition (location of images in the brain); pattern-recognition techniques for rapid assessment of burns

- Braynes, S. N., Head of Neurophysiological Laboratory. Algorithms of conditioned reflex development; neurocybernetics; self-organizing systems

Academy of Pedagogical Sciences, RSFSR

Institute of Psychology:

- Leont'ev, A. N. Information processes in man

Moscow State Pedagogical Institute:

- Grishchenko, N. M. Recognition of meaningful sentences

Scientific Research Institute of Defectology:

- Muratov, R. S. Reading devices

Academy of Sciences, USSR

Computer Center:

- Kozhukin, G. I. Self-teaching machines

Institute of Automation and Telemechanics: learning systems for recognition (machine to discern handwritten numerical figures)

- Ayzerman, M. A. Learning systems for recognition
- Bashkirov, O. A. Learning systems for recognition
- Braverman, E. M. Learning systems for recognition; "compactness hypothesis"
- Feldbaum, A. I. Machine intelligence
- Muchnik, I. B. Learning systems for recognition
- Shtil'man, Ye. V. Modeling instruction process using psychological learning theory

Institute of Biophysics: mathematical modeling of recognition processes; learning systems for recognition (identification of images by means of indices)

Bongard, M. M. Mathematical modeling of recognition processes; learning systems for recognition

Maksimov, V. V. Learning systems for recognition

Petrov, A. P. Learning systems for recognition

Smirnov, M. S. Learning systems for recognition

Vayntsvayg, M. N. Learning systems for recognition

Zenkin, G. M. Learning systems for recognition

Institute of Philosophy:

Novik, I. B. Modeling information processes

Institute of Physiology imeni Pavlov:

Anokhin, P. K. At Cybernetics Laboratory. Physiology and cybernetics

Laboratory of Electromodeling: site of Scientific Technical Conference on Cybernetics (1957)

Avrukh, M. L., editor of a VINITI publication. Reading devices

Gutenmakher, L. I. Director of Laboratory of Electromodeling. Electrical modeling of thought processes; automating information input

Kholsheva, A. F. Reading devices

Stretsiura, G. G. Reading devices

Mathematics Institute and Computer Center (Novosibirsk): self-teaching machines

Kozhukin, G. I. Self-teaching machines

Mathematics Institute imeni Steklov:

Kolmogorov, A. N. Parallel-operating automata; modeling thinking beings

Lyapunov, A. A., editor, *Problemy Kibernetiki*. General cybernetics

Lyubimskii, E. Z. Reading devices

Ofman, Yurii. Parallel-operating automata

Mathematics Institute imeni Steklov, Leningrad Department:

Varshavskii, V. I. Minimum description of images required for artificial recognition; pattern recognition with learning

Party Committee of the Presidium: Co-sponsored conference on "Philosophical Problems of Cybernetics"

Scientific Council on Cybernetics: general coordination of cybernetics research work; sponsored seminar on "Reading Devices"; co-sponsored conference on "Philosophical Problems of Cybernetics"

Parin, V., Chairman of Section on "Cybernetics and Living Nature" (Bionics)

Prokhorov, A.

Scientific Council on "Philosophical Problems of Natural Sciences": co-sponsored conference on "Philosophical Problems of Cybernetics"

Academy of Sciences, Latvian SSR

Institute of Electronics and Computer Technology:

Dambitis, Ya. Ya. (probably). Self-organizing systems

Institute of Physics:

Shneps, M. A. Self-organizing systems

Academy of Sciences, Ukraine SSR

Computer Center:

Glushkov, V. M. Machine intelligence; self-teaching/self-organizing systems; pattern recognition with learning; reading devices; recognition of meaningful sentences

Kovalevskii, V. A. Pattern recognition with learning; reading devices; automation of information input

Stognii, A. A. Recognition of meaningful sentences

Cybernetics Council: sponsored seminars on "Automation of Thinking Processes" and biocybernetics

Glushkov, V. M., Chairman of Cybernetics Council. Machine intelligence; self-teaching/self-organizing systems; pattern recognition with learning; reading devices; recognition of meaningful sentences

Stognii, A. A., Scientific Secretary of Cybernetics Council. Recognition of meaningful sentences

Institute of Cybernetics:

Gluskov, V. M. Director. Machine intelligence; self-teaching/self-organizing systems; pattern recognition with learning; reading devices; recognition of meaningful sentences

Institute of Electrical Engineering:

Ivakhnenko, A. G. Control theory in artificial intelligence; perceptron-type device

Mathematics Institute:

Amosov, N. M., Leader of Seminar on Biocybernetics

Kukhtenko, A. I. Self-organizing (control) systems

Other Institutes and Personnel Associated with Artificial-Intelligence

First Moscow Medical Institute, Department of Physiology:

Anokhin, P. K., Head of Department of Physiology. Physiology and cybernetics

Kazan Aviation Institute:

Borshche, V. B., published in *Trudy Kazan Aviatsionnyi Institut* (Works of the Kazan Aviation Institute). Machine intelligence

Il'in, V. V., published in *Trudy Kazan Aviatsionnyi Institut*. Machine intelligence

Rokhlin, F. Z., published in *Trudy Kazan Aviatsionnyi Institut*. Machine intelligence

Kiev Computer Center:

Kondratov, A., associated with work at Kiev Computer Center; writer on artificial intelligence

Kiev Institute of Civil Air Fleet imeni Voroshilov:

Kukhtenko, A. I. Self-organizing (control) systems

Laboratory (now Institute) for Systems for Transmission of Information:

Blokh, E. L. Minimum description of images required for artificial recognition; "compactness hypothesis"

Garmash, V. A. Quasi-topological approach to recognition; reading devices

Kharkevich, A. A. Minimum description of images required for artificial recognition

Kirillov, N. Ye. Automatic discrimination of speech sounds

Pereverzev-Orlov, V. S. (probably). Quasi-topological approach to recognition; reading devices

Tsirlin, V. M. Quasi-topological approach to recognition; reading devices

Latvian State University, Computer Center:

Arin', E. I. Self-teaching machines

Leningrad State University, Experimental Laboratory of Machine Translation:

Andreev, N. D. Reading devices

Military Air Engineering Academy imeni Zhukovskiy:

Chinayev, P. I. Self-teaching/self-organizing systems

Moscow Power Engineering Institute: brain modeling

Kushelev, Yu. N., Engineer. Neurocybernetics

Krug, G. K. Self-teaching machines

Letskii, E. L. Self-teaching machines; neurocybernetics

Svechinskii, V. B., student. Neurocybernetics, modeling thought processes

Moscow State University: site of continuing Cybernetics Seminar

Leont'ev, A. N. Information processing in man

Lyapunov, A. A., coordinator of Cybernetics Seminars. General cybernetics

Moscow State University, Department of Higher Nervous Activity:

Chichvarina, N. A. Algorithms of conditioned reflex development; neurocybernetics

Napalkov, A. V. Algorithms of conditioned reflex development; neurocybernetics; self-organizing systems

Semenova, T. P. Algorithms of conditioned reflex development; neurocybernetics

Shtil'man, Ye. V. Modeling instruction processes using psychological learning theory

Sokolov, Ye. N. Modeling perception

Turov, A. F. Algorithms of conditioned reflex development; neurocybernetics

Voloshinova, Ye. V. Algorithms of conditioned reflex development; neurocybernetics; modeling instruction processes using psychological learning theory

Order of Lenin Institute of Power:

Fel'dbaum, A. I., Faculty of Automation and Computer Technology. Machine intelligence

University imeni Palacki, Olomuc, Czechoslovakia, Chair of Psychology:

Golas, E. Generalization in pattern recognition and learning

Osladilova, D. Generalization in pattern recognition and learning

Valousek, C. Generalization in pattern recognition and learning

Zaporozhe Oblast Psychiatric Hospital:

Gasul', Ya. R. Modeling thought processes

Additional Personnel Associated with Artificial-Intelligence

Biryukov, B. V., contributor to *Problem Kirberneticki*

Blinkov, S. M. Structure of the brain

Fain, V. S. Minimum description of images required for artificial recognition; learning systems for recognition; automating information input

Fatkin, L. V., contributor to *Voprosy Psikhologii* (Questions of Psychology). Philosophical problems of cybernetics; automatic discrimination of speech sounds

Gutchin, Izrail', contributor to *Zarya Vostoka* (Dawn of the East), Tbilisi, Georgian SSR

Kamynin, S. S. Reading devices

Krisilov, A. D. Reading devices

Kubilyus, I., Prof., contributor to *Kommunist* (Vil'nyus). General cybernetics

Mayzel', N. I., contributor to *Voprosy Psikhologgi* (Questions of Psychology); philosophical problems of cybernetics

Mitulinskii, Yu. T. Minimum description of images required for artificial recognition

Petrenko, A. I., contributor to *Izvestiya Vuz* (News of Higher Educational Institutions). Reading devices

Poliakov, V. G., contributor to *Izvestiya AN SSSR* (News of the Academy of Sciences, USSR). Reading devices

Rozhanskaya, E. V. Mathematical theory of intelligibility (recognition)

Rybak, V. I. (probably Computer Center AS, UkSSR). Pattern recognition with learning

Saenko, G. I., editor of VINITI publication. Reading devices

Saparina, Ye. Brain modeling

Semenova, T. N. Pattern recognition with learning

Sindilevich, L. M., editor of VINITI publication. Reading devices

Sokolovskii, V. A. Minimum description of images required for artificial recognition

Svechnikov, S. V., contributor to *Izvestiya VUZ* (News of Higher Educational Institutions). Reading devices

Tarakanov, V. V. Perceptual activity in man

Tiukhtin, V. S. Theory of Images (and Perception)

Tsemel', G. I. Automatic discrimination of speech sounds

Vasil'ev, A. M., editor of VINITI publication. Reading devices

Vitushkin, A. G. Reading devices

Wang, Chih-ch'ing. Perceptual activity in man

Yeliseyev, V. K. Modeling recognition process

Zinchenko, V. P. Perceptual activity in man

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   Kolmogorov, A. N. "Life and Thinking from the Point of View of Cybernetics"

   Lyapunov, A. A. "On Control Systems in Living Nature and General Understanding of Living Processes"

   Glushkov, V. M. "Thinking and Cybernetics"

   Novik, I. B. "On the Nature of Information and the Peculiarities of Cybernetic Modeling"

   Fel'dbaum, A. I. "Instruction Processes for People and for Automata"
5. Mayzel', N. I. and L. V. Fatkin. "Conference on Philosophical Problems of Cybernetics," *Voprosy Psikhologii* (Questions of Psychology), Moscow, no 5, 1962 (JPRS: 17,574, 12 Feb 63)
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CENTRAL INTELLIGENCE AGENCY
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Office of Scientific Intelligence

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ARTIFICIAL-INTELLIGENCE RESEARCH IN THE USSR

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CENTRAL INTELLIGENCE AGENCY

OFFICE OF SCIENTIFIC INTELLIGENCE

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Project Officer

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PREFACE

Artificial-intelligence is a popular term that was coined in the United States during the 1950's to categorize research studies aimed at simulation of intelligent or "thinking" behavior. This type of research seeks to analyze the factors involved in the making, by humans, of specific types of decisions, to specify and define these factors as decision procedures or mathematical algorithms, and ultimately to fabricate hardware which can concretely model decision procedures and thereby assist human decision makers in making increasingly complex decisions. Although current digital computers can assist in the solving of some complex decision problems, artificial-intelligence research has already discovered decision routines which, while they can be modeled on a digital computer for demonstration purposes, are more efficiently solved with other types of hardware. In the future this will increasingly involve some sort of analog or combined analog-digital equipment, possibly a replica of the structure of the human brain, more likely a model abstracting essential elements of brain function on principles not yet uncovered.

Artificial-intelligence research is necessarily interdisciplinary in nature, involving such traditional areas as biology, physiology, psychology and electrical and systems engineering, with a strong under-laying of mathematics. As used in US literature, the term "artificial intelligence" may appear to be a rather flexible "tent," encompassing more or less whatever one desires to place within it. Nevertheless, artificial-intelligence is a "far out" field of scientific endeavor, the surface of which has been merely scratched. Its potential for future accomplishments can be only dimly seen and not evaluated at present. If it succeeds in significantly optimizing decision making in such complex areas as the economy or national strategic planning, it will obviously make a strong contribution to a relatively monolithic system, such as the Soviet one.

In the USSR, research on approaches to the fabrication of problem-solving or decision-making machines (that is, artificial-intelligence research) is conducted under the general category of cybernetics. This report covers Soviet research on major problems in this field, including pattern recognition by machines, machine learning, planning and induction in the problem-solving machine, and brain modeling. It does not cover conventional digital computer solution of problems or on-line computer control of processes.

The material in this report is based chiefly on information from the Soviet open literature available as of 1 May 1964. Additional information obtained through 1 July 1964 does not materially affect the conclusions.

CONTENTS

ARTIFICIAL-INTELLIGENCE RESEARCH IN THE USSR

PROBLEM

To assess artificial-intelligence research in the USSR.

CONCLUSIONS

1. In the Soviet Union, substantial governmental and Party support and encouragement are being given to extensive studies on the theory of artificial-intelligence. Soviet scientists of high caliber are conducting artificial-intelligence studies and are exposing young students to the state of the art in this interdisciplinary field, laying a sound foundation for further advances.

2. The importance which the Soviet regime attaches to artificial-intelligence research is attested by the unusual freedom of open discussion allowed scientists working in the field, as reflected in the published literature.

3. Soviet research in the theoretical and hardware aspects of artificial-intelligence is now about as advanced as US work and can be expected to continue at a rate equal to or greater than that observed in the West. Significant theoretical achievements within the next 5 years are highly probable. When theories are converted into designs, Soviet engineers probably will be able to produce the equipment.

SUMMARY

After a relatively late start, Soviet research on artificial-intelligence related to the ultimate development of decision-making machines now is about on a par with similar US work. The apparently greater rate of Soviet progress compared with that of the West is attributable to the magnitude of official recognition and support of artificial-intelligence research in the USSR. Soviet officials consider the development of decision-making machines to be essential to the successful management of their increasingly complex economic and social system, and are giving substantial support and Party encouragement to artificial-intelligence studies.

Soviet ideologists and scientists are discussing, from a wide range of viewpoints, the fundamental philosophical problems about the nature of intelligence and of man which are raised by attempts to model decision-making or intelligent behavior. The strictures of dialectical materialist dogma are not inhibiting research in this area. In view of the high prestige of the Soviet scientists taking part in these discussions and the publication in the Soviet scientific literature of the opinions expressed, artificial-intelligence studies represent rare and significant examples of intellectual freedom in the USSR.

Current Soviet work in the major subfields of artificial-intelligence research includes investigation of techniques for machine search of problem solutions, pattern recognition, machine learning, planning and induction in machine systems, and brain modeling. Soviet progress in research on machine techniques for search, pattern recognition, and learning compares favorably with US advances. Scientists and engineers engaged in research on pattern-recognition in the Soviet Union have made original contributions to the theoretical basis for artificial pattern-recognition systems and have fabricated various types of pattern-recognition devices.

Soviet research on simulation of such aspects of the cognitive process as learning and induction at present consists mainly of study of self-teaching and self-organizing systems. In these fields Soviet scientists and engineers have created models based on neuro-physiological conditioned-reflex approaches, on psychological learning theory, and on automatic control system theory.

Soviet study of the exceedingly complex problems involved in incorporating techniques of planning and induction in artificial problem-solvers is at a very early stage of development. As yet, little progress has been made in these fields in the West.

Research on the modeling of brain processes is receiving much emphasis in the USSR. Since 1955, laboratory experimentation on models that simulate neural processes has increased, and outstanding neuro-physiologists and psychologists have begun to work closely with mathematicians, computer specialists, and electronics engineers on cybernetic studies of brain-modeling problems.

Seminars are regularly offered to expose students to the state of the art in the fields that are especially significant to the future of artificial-intelligence research in the USSR. These seminars are conducted by the leading researchers in artificial-intelligence and are thereby laying a sound foundation for future advances in a new and multidisciplinary field.

DISCUSSION

INTRODUCTION

Since the mid-1950's, the Soviet government has increasingly emphasized the importance of a cybernetics research program for achieving national and international goals.* A large part of the theoretical research aspect of this program has been focused on the development of decision-making machines. Realization of such machines would assist the Soviets in solving two types of fundamental problems: (i) decision making on the basis of incomplete data (sometimes referred to as decision making under conditions of uncertainty), and (ii) decision making in the presence of complete but overwhelming quantities of data. Problems of the latter type are by definition beyond the capabilities of human decision makers. Problems of the first type, while inherently characteristic of human thinking activity, are rapidly extending beyond the bounds of possible human solution in the context of economic management and state administration.

*AEC: 828/46, "The Meaning of Cybernetics in the USSR," *Cybernetics in the USSR*, 30 Mar 64, [redacted] (b)(3)

Decision-making machines are, in essence, models of one variety or another of the human problem-solving process. Models of the human thinking or problem-solving process are artificial simulations of the information flow, or information processing, procedures of the human problem solver. The model may be mathematical, in which case it may be a program for a universal (digital) computing machine, or it may be a piece of hardware, such as an electronic circuitry analog. (Many decision procedures already elaborated by artificial-intelligence research are not efficiently modeled by the single-track, sequential method of operation of conventional digital computers. This would not be surprising in view of the apparent parallel operation of information processing in the human brain. Such decision routines can be modeled for demonstration purposes on a digital computer, but analog models of some sort will loom increasingly important in the fabrication of artificial-decision makers.) In any case, the essential feature of such a model is that for a given input of information the model shall produce at least the same output (of information) as does the natural process being modeled. Research on such models is categorized in the United States under the rubric "artificial-intelligence."

Soviet research on artificial-intelligence has mushroomed since 1956 along with other subproblems of cybernetics. After the establishment in 1959 of a national program for cybernetics, the direction of Soviet research on artificial-intelligence became one of the responsibilities of the Scientific Problem Council on Cybernetics of the Presidium, Academy of Sciences, USSR. The Cybernetic Machines Section of the Council appears to be the unit which assigns, monitors, and integrates most of this research work on a national scale. Actual research is conducted at the laboratories and institutes listed in the appendix. The number of facilities engaged in this research can be expected to grow as the cybernetic approach continues to permeate other areas of Soviet science and technology applicable to communication and control problems arising in production industries, the economy, law, government administration, and military activities.

Although much of the application-oriented cybernetics research is at present directed toward the realization of more sophisticated conventional systems for automatic control of machines, plants, space research vehicles, or even economic units, a large part of the theoretical research is related, directly or indirectly, to the development of "thinking machines," or "thinking cybernatons," as Soviet scientists often refer to them. Realization of such machines will have immediate relevance to information abstracting and retrieval, machine translation, and general problem solving, and eventual application to later-generation automatic control systems.

A. A. Lyapunov, a leading Soviet mathematician and editor of *Problems of Cybernetics*, has described the relationship of artificial-intelligence to general cybernetics and the nature of future control systems. He suggests that algorithmization (mathematical modeling) of thinking processes and of control processes is one of the most important aspects of cybernetic theory.[1] Other members of the Scientific Council on Cybernetics, in explaining the importance of artificial-intelligence, state that "the basic products of radioelectronics are various devices for automatic regulation, monitoring, control, and communications. The brain, which fulfills these functions in the living organism, works much more reliably and productively than any present-day radioelectronic machine. . . . Some first steps have already been taken in the direction of constructing practical automata analogous to the brain."[2]

PHILOSOPHICAL ASPECTS

Reexamination of basic philosophical attitudes toward the nature of the brain, of mind, and of man himself is taking place wherever artificial-intelligence research is being conducted. The Soviet Union is no exception. Philosophical-theoretical questions bearing on the simulation of intelligence, or intelligent behavior, are being thoroughly aired and in-

vestigated in Soviet scientific circles, outside as well as within the context of the fundamentals of dialectical materialism.[2-8]

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ARTIFICIAL-INTELLIGENCE RESEARCH IN THE USSR

PROBLEM

To assess artificial-intelligence research in the USSR.

CONCLUSIONS

1. In the Soviet Union, substantial governmental and Party support and encouragement are being given to extensive studies on the theory of artificial-intelligence. Soviet scientists of high caliber are conducting artificial-intelligence studies and are exposing young students to the state of the art in this interdisciplinary field, laying a sound foundation for further advances.

2. The importance which the Soviet regime attaches to artificial-intelligence research is attested by the unusual freedom of open discussion allowed scientists working in the field, as reflected in the published literature.

3. Soviet research in the theoretical and hardware aspects of artificial-intelligence is now about as advanced as US work and can be expected to continue at a rate equal to or greater than that observed in the West. Significant theoretical achievements within the next 5 years are highly probable. When theories are converted into designs, Soviet engineers probably will be able to produce the equipment.

SUMMARY

After a relatively late start, Soviet research on artificial-intelligence related to the ultimate development of decision-making machines now is about on a par with similar US work. The apparently greater rate of Soviet progress compared with that of the West is attributable to the magnitude of official recognition and support of artificial-intelligence research in the USSR. Soviet officials consider the development of decision-making machines to be essential to the successful management of their increasingly complex economic and social system, and are giving substantial support and Party encouragement to artificial-intelligence studies.

Soviet ideologists and scientists are discussing, from a wide range of viewpoints, the fundamental philosophical problems about the nature of intelligence and of man which are raised by attempts to model decision-making or intelligent behavior. The strictures of dialectical materialist dogma are not inhibiting research in this area. In view of the high prestige of the Soviet scientists taking part in these discussions and the publication in the Soviet scientific literature of the opinions expressed, artificial-intelligence studies represent rare and significant examples of intellectual freedom in the USSR.

Current Soviet work in the major subfields of artificial-intelligence research includes investigation of techniques for machine search of problem solutions, pattern recognition, machine learning, planning and induction in machine systems, and brain modeling. Soviet progress in research on machine techniques for search, pattern recognition, and learning compares favorably with US advances. Scientists and engineers engaged in research on pattern-recognition in the Soviet Union have made original contributions to the theoretical basis for artificial pattern-recognition systems and have fabricated various types of pattern-recognition devices.

Soviet research on simulation of such aspects of the cognitive process as learning and induction at present consists mainly of study of self-teaching and self-organizing systems. In these fields Soviet scientists and engineers have created models based on neuro-physiological conditioned-reflex approaches, on psychological learning theory, and on automatic control system theory.

Soviet study of the exceedingly complex problems involved in incorporating techniques of planning and induction in artificial problem-solvers is at a very early stage of development. As yet, little progress has been made in these fields in the West.

Research on the modeling of brain processes is receiving much emphasis in the USSR. Since 1955, laboratory experimentation on models that simulate neural processes has increased, and outstanding neuro-physiologists and psychologists have begun to work closely with mathematicians, computer specialists, and electronics engineers on cybernetic studies of brain-modeling problems.

Seminars are regularly offered to expose students to the state of the art in the fields that are especially significant to the future of artificial-intelligence research in the USSR. These seminars are conducted by the leading researchers in artificial-intelligence and are thereby laying a sound foundation for future advances in a new and multidisciplinary field.

DISCUSSION

INTRODUCTION

Since the mid-1950's, the Soviet government has increasingly emphasized the importance of a cybernetics research program for achieving national and international goals.* A large part of the theoretical research aspect of this program has been focused on the development of decision-making machines. Realization of such machines would assist the Soviets in solving two types of fundamental problems: (i) decision making on the basis of incomplete data (sometimes referred to as decision making under conditions of uncertainty), and (ii) decision making in the presence of complete but overwhelming quantities of data. Problems of the latter type are by definition beyond the capabilities of human decision makers. Problems of the first type, while inherently characteristic of human thinking activity, are rapidly extending beyond the bounds of possible human solution in the context of economic management and state administration.

*AEC. 828/46, "The Meaning of Cybernetics in the USSR," *Cybernetics in the USSR*, 30 Mar 64, [redacted]

(b)(3)

Decision-making machines are, in essence, models of one variety or another of the human problem-solving process. Models of the human thinking or problem-solving process are artificial simulations of the information flow, or information processing, procedures of the human problem solver. The model may be mathematical, in which case it may be a program for a universal (digital) computing machine, or it may be a piece of hardware, such as an electronic circuitry analog. (Many decision procedures already elaborated by artificial-intelligence research are not efficiently modeled by the single-track, sequential method of operation of conventional digital computers. This would not be surprising in view of the apparent parallel operation of information processing in the human brain. Such decision routines can be modeled for demonstration purposes on a digital computer, but analog models of some sort will loom increasingly important in the fabrication of artificial-decision makers.) In any case, the essential feature of such a model is that for a given input of information the model shall produce at least the same output (of information) as does the natural process being modeled. Research on such models is categorized in the United States under the rubric "artificial-intelligence."

Soviet research on artificial-intelligence has mushroomed since 1956 along with other subproblems of cybernetics. After the establishment in 1959 of a national program for cybernetics, the direction of Soviet research on artificial-intelligence became one of the responsibilities of the Scientific Problem Council on Cybernetics of the Presidium, Academy of Sciences, USSR. The Cybernetic Machines Section of the Council appears to be the unit which assigns, monitors, and integrates most of this research work on a national scale. Actual research is conducted at the laboratories and institutes listed in the appendix. The number of facilities engaged in this research can be expected to grow as the cybernetic approach continues to permeate other areas of Soviet science and technology applicable to communication and control problems arising in production industries, the economy, law, government administration, and military activities.

Although much of the application-oriented cybernetics research is at present directed toward the realization of more sophisticated conventional systems for automatic control of machines, plants, space research vehicles, or even economic units, a large part of the theoretical research is related, directly or indirectly, to the development of "thinking machines," or "thinking cybernatons," as Soviet scientists often refer to them. Realization of such machines will have immediate relevance to information abstracting and retrieval, machine translation, and general problem solving, and eventual application to later-generation automatic control systems.

A. A. Lyapunov, a leading Soviet mathematician and editor of *Problems of Cybernetics*, has described the relationship of artificial-intelligence to general cybernetics and the nature of future control systems. He suggests that algorithmization (mathematical modeling) of thinking processes and of control processes is one of the most important aspects of cybernetic theory.[1] Other members of the Scientific Council on Cybernetics, in explaining the importance of artificial-intelligence, state that "the basic products of radioelectronics are various devices for automatic regulation, monitoring, control, and communications. The brain, which fulfills these functions in the living organism, works much more reliably and productively than any present-day radioelectronic machine. . . . Some first steps have already been taken in the direction of constructing practical automata analogous to the brain."[2]

PHILOSOPHICAL ASPECTS

Reexamination of basic philosophical attitudes toward the nature of the brain, of mind, and of man himself is taking place wherever artificial-intelligence research is being conducted. The Soviet Union is no exception. Philosophical-theoretical questions bearing on the simulation of intelligence, or intelligent behavior, are being thoroughly aired and in-

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maintained by some at the conference that consciousness necessarily includes a subjective element with a specific character which is the result of the labor and social relations in which people engaged during the process of social evolution.

A more empirical approach to consciousness was advanced at the conference by those scientists interested in modeling the structure which embodies human consciousness, that is, the brain. Although a structural model of the human brain is far beyond present technological and scientific capabilities, the possibility of its future realization is considered to be worth discussion by the Soviets. A. N. Kolmogorov, world renowned mathematician, is optimistic about the chances of success in brain-modeling ventures. He called for the freeing of definitions of life and thought from arbitrary premises and for the redefinition of these concepts along purely functional lines. Kolmogorov believes that if the functional point of view toward life and thought is subscribed to, the conclusion is inevitable that replication of the organization of a system can be accomplished by organizing different elements into a new system which would have the essential traits and structure of the system being modeled. From this Kolmogorov concluded that:

> A sufficiently complete model of a living being can in all justice be called a living being and the model of a thinking being, a thinking being. It is important distinctly to understand that within the limits of a materialistic ideology there do not exist any kind of well-grounded, principal arguments against a positive answer to [this] question. This positive answer is the contemporary form of the attitude concerning the natural origin of life and the material basis of consciousness.

The extreme empirical view advanced by the Kolmogorov school seems to be in the ascendancy. For example, several points of view on the question, "Can a machine think?" have been reviewed by a group of authors in the *Works of the Kazan Aviation Institute*, a somewhat surprising source for discussions of philosophical aspects of artificial-intelligence.[6] The group did not find convincing any of the arguments against the possibility of creating a thinking machine. The subject of the negative arguments considered by them ran the gamut from the algorithmic insolvability of some problems, and the irreducibility of the thinking process to a physical operation, to the impossibility of modeling the subjective-psychological world of man. The Kazan group points out in rejecting such arguments, that cybernetics provides the first basis for (i) uncovering the elements involved in consciousness and cognition and (ii) "resolving positively the question of the possibility of creating a thinking machine." The Kazan group does not recognize the brain as the only highly organized material system in which consciousness can develop, and forecasts that highly organized material systems of another type, in which consciousness develops, are possible and realizable.

V. M. Glushkov, one of the most politically powerful among Soviet cyberneticists,* sides with Kolmogorov and the Kazan group. Recently, in discussing the possibilities of machine intelligence, he contrasted cybernetic systems with earlier mathematico-logical and other formal language approaches to modeling the thought processes. He found significant advances in the cybernetic approach. Glushkov would describe any control or cognitive system as a cybernetic system which can be analyzed as an abstract [informational] model. For this purpose, both the input and output information, that is, all of the information which a system exchanges with the outside world, can be conceived as being encoded in words of a given standard alphabet. All of the activity of the cybernetic system may thus be reduced to the transformation of words in a standard alphabet. The study of a given cybernetic system can be reduced thusly to the determination of rules according to which the indicated transformation occurs. Glushkov noted that among these rules there may be some which permit certain

*V. M. Glushkov is Vice President of the Academy of Sciences, Ukrainian Soviet Socialist Republic; Director of the Institute of Cybernetics in Kiev; Chairman of the Cybernetics Council of the Ukrainian Academy; and Chairman of the recently created Interdepartmental Council for the Introduction of Mathematical Methods and Electronic Computers in the National Economy, which is under the State Committee for Coordination of Scientific Research of the Council of Ministers, USSR.

chance transformations, as well as some that permit the altering of other rules of information conversion in the course of time under the influence of an infinite surrounding medium. Appreciating the possible infinitude of the system of rules defining the regularities of the informational activity of the brain, Glushkov believes that the modeling of a sufficiently large number of the essential rules in the brain system eventually will result in a behavior pattern of the model (on the informational level) which will correspond to brain activity.[8] Glushkov has asserted that, since modern electronic digital computers possess "algorithmic universality* . . . it is theoretically possible to model [on the informational level] any thought processes with the aid of such machines."[8, p. 10]

At least as significant as the content of these epistomological disputations is their wide distribution in popular and Party media. Typical of "thinking machine" discussions is an article in *Znaniye-Sila* (*Knowledge is Power*, a popular-science type of magazine). It describes the parallel mode of operation of the brain (carrying out several calculations or decision procedures simultaneously) versus the series (single-track) nature of contemporary electronic computing apparatus and points out the advantage of the former in efficiency and universality. It reports that Soviet researchers are studying the operating principles of automata which work in parallel instead of in series.[9]

Soviet research in artificial-intelligence is motivated by the anticipated necessity of using machines in place of people in situations where speed, complexity, or other characteristics of control processes exceed the capability of man. The Soviet policy regarding the use of "thinking machines" was expressed in a recent edition of *Kommunist*. The development of technology, with the increase in speed and accuracy requirements of separate production operations and the growth of the entire technological process as a whole, was said to have begun to exceed, in most cases, man's power to control them. The *Kommunist* article concludes that it is necessary to replace even the psychic activity of man in such cases with automatic control machines.[10]

*That is, computers can perform any information transformation on the basis of a program (algorithm) built out of their available elementary instructions, if these include rules which define chance transformations and instructions by which certain alterations are made in the system of rules.

PRINCIPAL RESEARCH PROBLEMS

The "tent-like" character of artificial-intelligence research has resulted in a somewhat chaotic state in this field of science.[11-13] There are several schools, each represented by spokesmen as critical of other schools as they are competent in the techniques of their own. The result is a lack of standardized criteria for use in assessing Soviet research in the field of artificial-intelligence. Thus, an expert in one popular US approach, upon discovering a lack of comparable work in the USSR, will give a negative evaluation of Soviet research in artificial-intelligence. On the other hand, the opponents of that particular US expert will argue that the absence of such research in the USSR signifies that the Soviets have withdrawn from a blind alley of investigation. Many of these conflicts are semantic; almost all of the approaches to artificial-intelligence share a common set of problems. When Soviet research on these problems is compared with US approaches to the same problems, regardless of "schools," the USSR and the US are found to be approximately on a par.

There are differences in emphases, however, between Soviet and US approaches to these shared problems. US scientists tend to emphasize mathematical or machine models of human cognitive processes. Many Soviet researchers on the other hand consider that the human brain has reached certain limits in regard to its capabilities for memory and operational speed after a long process of slow evolutionary development.[14] The resultant qualities of the human brain, therefore, are not believed by the Soviets to be equal to all the tasks modern men must face. According to them, a machine that might be a perfect analog of the brain, for instance, will not do any better than the brain when faced with such tasks. Therefore, if the ever more complex problems are to be solved, machine "brains" surpassing those of men must be built. M. V. Keldysh, President of the Academy of Sciences, USSR, in making this point asserts: "We must copy nature's processes in technology creatively rather than literally, with full knowledge of nature and of technology so that we may select techniques which will give us better results than those achieved in nature."[15] The natural processes to be copied "creatively" in the Soviet research program are the same processes investigated by US scientists of most schools concerned with artificial-intelligence. These are search, pattern recognition, learning, planning, and induction.[16]

Search and Pattern Recognition

The first approach to machine solution of a problem is search. Given a problem, a contemporary data-processing machine in the USSR as elsewhere, can search rapidly by trial and error through a large number of possible solutions for a valid solution to the given problem. Nevertheless, in solving complex non-trivial problems, the number of possible solutions is so large that this trial-and-error methodology becomes excessively time-consuming in practical operation.

Soviet scientists recognize that a large reduction in search time, although bringing some real problems into the realm of practical machine solution, could be achieved by the introduction of pattern-recognition techniques. The machine that is designed with pattern-recognition aids-to-search could classify problems into categories amenable to certain types of solutions. The current state of Soviet and Western research suggests that such techniques are nearing practicability for more and more complex patterns.

Theoretical studies for pattern-recognition devices began in the USSR as early as 1953.[17-20] The philosophical, physical, and psychological bases of perception were extensively discussed in *Voprosy Psikhologii* (Questions of Psychology) in 1959.[21] More recently, Soviet researchers have accomplished considerable work on the specifics of minimum descriptions of images that are required for recognition by artificial systems.[22-27]

The works of E. L. Blokh, mathematician at the Institute for Information Transmission Systems and E. M. Braverman of the Institute of Automation and Telemechanics are notable among recent approaches to practical solutions of recognition problems. Braverman has originated a "compactness hypothesis"* as a theoretical basis for solution of such problems. Several Soviet researchers are using this theory as a basis for development of specific recognition techniques. E. L. Blokh is using certain operations to compute the distance and angle between elements, representing various patterns presented, in an n-dimensional configuration space. This appears to be a promising mathematical modeling approach to a large class of pattern-recognition problems.[29]

Pattern-recognition modeling studies are being supported by research on perception from the psychological and physiological points of view. One investigation involved the establishment and development of perceptual activity in 3- to 6-year-old children. Eye movements of the subjects were observed and recorded photographically as the children examined (for learning) and later recognized pictures presented to them. The eye movements recorded were then compared with measures of the recognition ability of the children at different ages.[30] Another study was devoted to identification of objects in the visual system. Time required for subjects to recognize simple objects, formed of small numbers of elements, correlated well with an information theory model for such recognition that was based on earlier findings on information collating and processing activity in the eye system.[31]

*The "compactness hypothesis" is formulated as follows: Patterns presented to the artificial system are characterized by a number of criteria equal to n. The values of the n criteria are used to establish points in an n-dimensional configuration space. Each point represents an individual pattern. All points representing patterns which are similar, for example, all letters "A," all figures "5," all pictures of cats, will tend to lie in "compact" regions of the space, with relatively easily discernible separations between regions.[28]

Soviet work in the area of realization of physical models to perform pattern recognition has been reported. At a 1957 Scientific-Technical Conference on Cybernetics, one reading device for an information machine was described.[32] At an All-Union Conference on Machine Translation, held at Moscow State University in May 1958, reports on principles of constructing electronic reading devices were heard, and a device "enabling the blind to read ordinary typographic text" was described.[33 34] (The latter device has been pictured in the Soviet press, but its operating principles were not described in publication.) Hardware modeling of pattern-recognition schemes is being conducted by A. A. Kharkevich, the well-known radio engineer, as well as others.[35-37 51] Some of this research is directed toward the specific application of automating the input of information into computing machines.[38-41]

A quasi-topological method of distinguishing and identifying letters has been developed and realized in hardware by a group of researchers of the Institute for Systems for Transmission of Information (Moscow).[42 43] This makes use of scanning the contour of a letter with a light spot and identifying its topological characteristics (ends of lines, and junctions of lines), which are recorded in a binary code. Since this will not separate all Cyrillic letters, some of which are topologically identical, further geometric analysis is used to analyze topologically redundant groups. Such a scheme is basically sound in theory and relatively easily realized in hardware, but system "noise" (disconnected lines or smudged letters) may be hard to deal with, and no figures have been published on reliability of recognition accomplished.

In June 1960, the Scientific Council on Cybernetics sponsored a seminar on reading devices. This seminar considered the principles of constructing such machines and creating corresponding systems for coding the information involved.[44] Five different machines under development for automatic pattern recognition were described by V. M. Glushkov (letter recognition by line scan and minimal description); V. A. Kovalevskiy (image scanning by following the outlines of letters); A. D. Krisilov (identification of constant features of letters by means of standard television techniques); V. M. Tsirlin (the quasi-topological method) and A. G. Vitushkin (a computer manipulated system for analyzing Cyrillic letters which separates characteristic features by means of vertical line scanning). In addition, E. M. Braverman and V. S. Fayn presented papers on recognition systems employing learning (that is, performing identification on the basis of criteria not given beforehand).

Studies on the mathematical modeling of recognition processes on electronic digital computers have been conducted by M. M. Bongard, an outstanding young biophysicist.[45-47] A report of his in the Cybernetics Council collection *Biologicheskiye Aspekty Kibernetiki—Sbornik Rabot* (Biological Aspects of Cybernetics—Collected Works) describes the methodology and prospects of recently begun research aimed, first, at bridging the gap between physiological study of optical receptor activity and the modeling of recognition, using a universal digital computer.[47] However, Bongard alludes to the disadvantage of this model in contrast to the parallel information processing employed in human recognition activity. He foresees, therefore, the development of a "logic of recognition . . . a logic such that it could be used in an analog computer. In essence, such a machine will be a model of part of the human brain."

Principles for constructing a "universal reading" machine have been developed by V. M. Glushkov.[48] This scheme uses a cathode ray tube-type receptor, a computer to control the trace and to compute the description of the pattern presented, and a technique of comparison against descriptions prestored in the memory for identifying patterns presented. The author admits that the scheme described is unnecessarily cumbersome for the recognition of such simple stylized patterns as digits or letters, but points to its usefulness for "reading" complex contours or semitone pictures. Such a "universal reading automaton" has been built at the Computing Center of the Academy of Sciences, Ukrainian SSR, and is used in conjunction with a "Kiev" computer.

A somewhat different "machine that reads" has been developed at the Ukrainian Academy Computer Center under the direction of Candidate of Technical Sciences, V. A. Kovalevskiy.[49,50] This system reportedly failed to recognize only 2 of 35,000 numbers produced with a portable typewriter, including half printed and otherwise distorted samples. In using this method for recognition, according to Kovalevskiy, the maximum of the correlation coefficient for an unknown image and of each of the standard images is sought, the latter images being subjected to all possible transformations. When this is done, all normally typed letters, as well as most of those artificially marred, are correctly recognized and identified, with the statistical error of incorrect recognition not exceeding 10^{-4}.

For solving a more general problem of recognizing nonstandard letters and numbers, an algorithm is being developed which is based on dichotomy, that is, sequential division of the set of all images into two classes. Kovalevskiy believes that such an algorithm will make it possible to work with an alphabet containing many characters and will assure rapid recognition with a comparatively small memory capacity.

Learning, Induction, and Planning

Further improvement in machine problem-solving efficiency could be accomplished with the addition of a learning capability. The machine would then be able to apply readily its already proven methods to the solution of problems that are new but similar to problems previously encountered in the machine's experience. Radical reductions of search time could be realized through the application of planning methods: the machine would survey and analyze the solution space and plan the best way for its detailed examination. Furthermore, to manage broad classes of very complex problems, the machine, as the human, must construct and internalize a model of its environment, that is, it must employ some scheme of induction.

Research on planning and induction in artificial systems is at a rather early stage of development in the USSR, as it is in the West. Progress is occurring, however, in fields contributing to the development of machine learning, induction and planning. Such supporting research includes studies on information theory, coding theory, brain modeling, statistical decision theory, automata theory, and heuristic programming. Pertinent Soviet literature often treats these subjects as conjoined in such studies as pattern recognition employing learning, other learning systems, self-organizing systems, or brain models.

Learning appears to be an essential characteristic of more efficient and truly universal pattern-recognition systems, just as it is of more efficient problem-solving apparata in general. Soviet researchers in the field of learning systems like Braverman, Glushkov, and Mark Ayzerman,* compare favorably with their Western counterparts. Furthermore, they are working on essentially the same types of studies: perceptron-type systems, algorithms for teaching the recognition of shapes, and computer programs for recognition of pattern configurations.[44,51-63]

Investigations of learning systems for recognition are being conducted at a variety of Soviet scientific establishments. At the Institute of Automation and Telemechanics in Moscow, a machine was programmed to discern numerical figures written in different handwritings. According to Soviet reporters, in only a few cases did the machine give erroneous responses, even when confronted with previously unseen figures. The Institute of Surgery of the Academy of Medical Sciences is testing the hypothesis that a "compact area" is formed in the brain of an animal or a human by variants of a similar image. The Institute of Biophysics of the Academy of Sci-

*M. A. Ayzerman is a Doctor of Technical Sciences in mathematics and electronics at the Institute of Automation and Telemechanics, Moscow.

ences is attempting to program a machine that will identify indices of an image and, on the basis of the indices, to recognize the image. In each of the experiments, errors were made by the machine. However, the Soviets believe that the important fact is that the machine is capable of accumulating experience, with the result that its qualifications are increasing and its errors are gradually decreasing.[55]

M. A. Ayzerman's latest experiments involve the teaching of a machine to recognize patterns without a need for pre-introduced criteria. Starting from a basis in Braverman's "compactness hypothesis," Ayzerman develops two algorithms by which a machine can "learn" to distinguish between the compact areas representing different images in a configuration space, thus separating and recognizing the images. The first algorithm has the machine construct, one by one, random hyperplanes whose only criterion is that they separate points which the machine is told (that is, training process) represent different objects. Ending up the training phase with a series of intersecting hyperplanes, the machine then examines these and "washes out" sections of planes which do not perform the separating function, thereby leaving a series of broken hyperplanes which effectively separate areas containing points representing different images. In using the second algorithm, the machine constructs positive potential surfaces (functions) decreasing away from, respectively, each point or set of points representing images of the same object. Identification of a test image (point) is accomplished by (first algorithm) determining on which side of the hyperplanes the point lies, or (second algorithm) determining which potential surface (function) has the highest value at the test point. Tests were conducted with five digits (0, 1, 2, 3, 5), each written 160 different ways. Using 40 samples of each digit for training, and 120 for test, the machine achieved 83–89 percent correct recognition with the first algorithm. With "paralleling" of seven variations of a digit in the training process, 98 percent correct response was achieved. The training sequence filled 1,500–3,000 binary digits in machine memory. The second algorithm was tested using 10 samples of each digit for training and 150 for testing and resulted in 100 percent correct recognizance. Additionally, the second algorithm was tested on the 10 digits from 0 to 9, with 10 samples for training and 140 for test on each digit, and achieved 85 percent correct response.[28 56 57] Ayzerman's second algorithm is very similar to that employed in a US device now becoming operational for the identification of sonar contacts.

Pattern-recognition techniques are employed at the Institute of Surgery imeni Vishnevskii, Moscow, to achieve rapid assessment of the area and seriousness of burns.[64] The algorithm, for recognition of objects with many parameters, employs learning. The system is "trained" on case histories. When vital information, such as burn area and location and patient's age, is fed in, the computer identifies and stores symptoms and other factors. It also identifies objective criteria for forecasting the outcome of the illness. The system was tested on additional case histories with known outcomes, and the prognoses in most cases agreed with the actual course and outcome of the injury.

Many of the Soviet attempts to realize models of learning, induction, and other aspects of the cognitive process are carried on under the classification of self-teaching (or learning) systems, or of self-organizing systems. A significant portion of research in these areas has apparently not been published. In a number of cases the titles of papers discussed at meetings and seminars have been published, but the contents of the papers are unavailable to the West. Thus, a self-teaching machine based on a program model was discussed at the First All-Union Meeting on Computer Mathematics and Computing Technology held in 1959, but details have not been circulated to the West. Other self-teaching machines were alluded to (but only in general terms) at cybernetics seminars at Kiev and Moscow State Universities.[65-67] Since its inception in 1955, the latter seminar, conducted by the outstanding cyberneticist A. A. Lyapunov, has held biweekly sessions throughout the school year on a wide range of subjects related to cybernetics.

Application of principles from automatic control theory to self-organizing systems study is exemplified by the work of the well-known control engineer and mathematician, A. G. Ivakhnenko. He has surveyed and categorized various types of "learning" and "self-learning" (that is, new information generating) systems and has related US to Soviet work on some of these types. Ivakhnenko is studying the application of the theory of invariance and the principles of combined control systems to the development of certain (self) learning systems. Control principles apply to the memory part of the system, that is, to the control of the selection and accumulation of information in the memory. Ivakhnenko is specifically interested in a perceptron-type device, a scheme first developed in the United States.[68, 69] Ivakhnenko's perceptron device apparently employs some variations and innovations in comparison to similar US devices.[70]

Modeling the processes of instruction with automatic systems was discussed in a 1962 collection on automatic regulation and control. Starting from the learning theories of Thorndike, Gestalt psychology and I. P. Pavlov, the authors discussed various machine learning systems. Among the Western and Soviet systems discussed were the perceptron and the approaches of the US scientists Newell, Simon and Shaw, Gelernter and Rochester, and O. Selfridge, the UK scientist, Andrew, and the Special Design Bureau of Moscow Power Engineering Institute. The Soviets view training as a process of changing algorithms, and propose that "a system which finds by means of automatic search an algorithm of action which is successful from any determined point of view and which was not put into the system by man before the training process, should be called a learning system." [71]

Closely related to systems embodying self-learning are those capable of self-organization.* Soviet scientists evinced interest in the theory of self-organizing systems as early as 1959. In that year, S. N. Braynes and A. V. Napalkov wrote on the subject for *Voprosy Filosofii* (Questions of Philosophy). In that study, the investigators related the development of such systems to their work on conditioned-reflex modeling. They foresaw the realization of "an algorithm of operation for self-organizing cybernetic systems, ensuring the formation of new programs for operation without the undertaking of 'exhaustive search' of all possible variants." [73]

Considerable attention was devoted to self-organizing systems at an All-Union Meeting on Computer Mathematics and Computing Technology (1959) and at a symposium on Principles of Design of Self-Learning Systems held in Kiev during 1961. Comparison of the published papers from the latter symposium with those given at the first US Interdisciplinary Conference on Self-Organizing Systems in 1959 reveals very similar topic coverage and a similar level of achievement reflected at the two conclaves. As of 1961, the Soviets were 2 to 3 years behind the United States in this particular area of artificial-intelligence research.[74–78]

Brain Modeling

Historically, there has been a large amount of Russian neurophysiological research since the early 19th century, but its mathematicization is a recent innovation. Brain research now is very much concerned with the algorithmization and modeling of the information transactions which take place in living organisms. These studies play an important role in cybernetics/artificial-intelligence re-

*M. C. Yovits, Chairman of the First and Second Conferences on Self-Organizing Systems, Chicago, 1960 and 1962, considers these areas of artificial-intelligence research to be of great significance. To Yovits it appears that "certain types of problems, mostly those involving inherently non-numerical types of information, can be solved efficiently only with the use of machines exhibiting a high degree of learning or self-organizing capability. Examples of problems of this type include automatic print reading, speech recognition, pattern recognition, automatic language translation, information retrieval, and control of large and complex systems. Efficient solutions to problems of these types will probably require some combination of a fixed stored program computer and a self-organizing machine." [72]

search and are conjoined with attempts to simulate artificially the pattern recognition, learning, planning and induction processes.

Before research could begin in this new field, the whole area of physiology and cybernetics had to be broken out of the restraints of Pavlovian doctrine. The beginning of this break was apparent in a 1955 review of the subject by the well-known Soviet physiologist P. K. Anokhin in *Questions of Philosophy* (*Voprosy Filosofii*).[79] Laboratory experimentation in the modeling of brain processes began shortly thereafter. Some of the earliest work was reported at a Scientific-Technical Conference on Cybernetics, held at the Laboratory of Electromodeling of the Academy of Sciences, USSR, in May 1957. L. I. Gutenmakher, Director of the Laboratory, described work on the electrical modeling of certain mental work processes using "information machines with large internal storage."[80] Research into the structural makeup of the human brain was discussed at the Seminar on Cybernetics at Moscow State University in 1960.[81]

After an artificial-intelligence slant to traditional neuroanatomy and neurophysiology became evident in efforts to model the brain, a new type of interdisciplinary scientist emerged. A. V. Napalkov of the Faculty of Higher Nervous Activity at Moscow State University could well be described as the first of this new breed of physiologist-cyberneticist. In early 1959 he co-authored, with a medical doctor and an engineer, a study which surveys cybernetics and physiology in general, including the theory of automata. Furthermore, these scientists describe the results of studies on brain activity in terms of a search for algorithms representing systems capable of independent development of new programs for their operation, and those able to form new behavior patterns on the basis of processing information accumulated earlier. They also described an artificial device which, in a primitive way, simulates these learning processes, that is, a "learning automaton," and which was developed at the Moscow Power Engineering Institute in cooperation with the life scientists.[82]

More intensive investigations into the information processing procedures of the brain, still in terms of the development of chains of conditioned reflexes, were described by Napalkov in 1960.[83] In 1962, the researchers in the Department of Higher Nervous Activity reported findings which showed increasing sophistication in the greater complexity of the algorithms of information processing that had been derived. By 1962, a much more sophisticated "learning machine," based on the algorithms defined by the neurophysiologists, and exhibiting some capability at "self-organization" (that is, self-improvement), had been fabricated by the engineers at the Power Engineering Institute. This group worked with the neurophysiological laboratory of S. N. Braynes, co-worker and co-author with Napalkov.[84]

Soviet Bloc researchers are also investigating the mode of operation of brain processes from the point of view of psychology. The work of a Czech, E. Golas, on the conditions of generalization in pattern recognition and learning falls into this class of research. His experiments involved a statistical analysis of the process of generalization as manifested by subjects perceiving common elements among sets of stimuli (objects) presented. This study, clearly of a preliminary nature, served only to demonstrate that wide variations characterize the conditions for generalization.[85]

New centers for brain research along cybernetic lines are now being established at the Brain Institute, Institute of Physiology, Institute for Information Transmission Problems and at installations outside the Moscow-Leningrad complex. At Kiev, for example, students are offered the opportunity to obtain training in the most advanced areas of artificial-intelligence research, and specifically brain modeling. In 1962, two seminars were held under the auspices of the Cybernetics Council of the Ukrainian Academy of Sciences. The first, on "Automation of Thinking Processes," was conducted by V. M. Glushkov, chairman of the Council. This seminar covered: (i) the foundations and particularities of thought processes that are characteristic of man in the creative sphere of his activity, and the possibilities of their algorithmic description; (ii) modeling on contemporary computers of such processes as pattern recognition, recognition of concepts, identification of meaningful sentences, deduction of logical consequences, proving theorems, selections of strategies in games, and composition of music; (iii) learning as a basis for modeling the mental activity of man; (iv) theory of self-teaching systems and practical development of algorithms incorporating learning; and (v) correlations between precise (to the degree possible) modeling of creative processes and the specifics of machine algorithms simulating these processes.

The second seminar, at the Ukrainian Academy, was led by Doctor of Medical Sciences, N. M. Amosov. Problems associated with biocybernetics and the application of electronics in biology and medicine were considered at this seminar. Specific topics included (i) application of information theory in biology and medicine; (ii) principles of automatic control in biological systems and their peculiarities; (iii) some principles of coding information in the nervous system; (iv) perception and transformation in receptors and the central nervous system; (v) contemporary hypotheses on the nature of nerve excitation from the position of biocybernetics; (vi) some questions of modeling elements of the central nervous system; (vii) thinking and the psychic activity of man; (viii) principles of forming self-organizing neuron nets and bionics; (ix) control of the processes of excitation and inhibition in the central nervous system by means of electrical and electromagnetic influences; and (x) cellular biology in the light of biocybernetics.[86]

APPENDIX

Institutes and Scientists Associated with Research of Artificial-Intelligence Significance in the Soviet Bloc

Academy of Medical Sciences, USSR

Institute of the Brain:

- Glezer, V. D. Retinal activity in identification
- Nevskaya, A. V. (probably). Retinal activity in identification
- Seredinskii, A. V. (probably). Retinal activity in identification
- Tsukkerman, I. I. (probably). Retinal activity in identification

Institute of Surgery imeni Vishnevskii: learning systems for recognition (location of images in the brain); pattern-recognition techniques for rapid assessment of burns

- Braynes, S. N., Head of Neurophysiological Laboratory. Algorithms of conditioned reflex development; neurocybernetics; self-organizing systems

Academy of Pedagogical Sciences, RSFSR

Institute of Psychology:

- Leont'ev, A. N. Information processes in man

Moscow State Pedagogical Institute:

- Grishchenko, N. M. Recognition of meaningful sentences

Scientific Research Institute of Defectology:

- Muratov, R. S. Reading devices

Academy of Sciences, USSR

Computer Center:

- Kozhukin, G. I. Self-teaching machines

Institute of Automation and Telemechanics: learning systems for recognition (machine to discern handwritten numerical figures)

- Ayzerman, M. A. Learning systems for recognition
- Bashkirov, O. A. Learning systems for recognition
- Braverman, E. M. Learning systems for recognition; "compactness hypothesis"
- Feldbaum, A. I. Machine intelligence
- Muchnik, I. B. Learning systems for recognition
- Shtil'man, Ye. V. Modeling instruction process using psychological learning theory

Institute of Biophysics: mathematical modeling of recognition processes; learning systems for recognition (identification of images by means of indices)

- Bongard, M. M. Mathematical modeling of recognition processes; learning systems for recognition
- Maksimov, V. V. Learning systems for recognition
- Petrov, A. P. Learning systems for recognition
- Smirnov, M. S. Learning systems for recognition
- Vayntsvayg, M. N. Learning systems for recognition
- Zenkin, G. M. Learning systems for recognition

Institute of Philosophy:

- Novik, I. B. Modeling information processes

Institute of Physiology imeni Pavlov:

- Anokhin, P. K. At Cybernetics Laboratory. Physiology and cybernetics

Laboratory of Electromodeling: site of Scientific Technical Conference on Cybernetics (1957)

- Avrukh, M. L., editor of a VINITI publication. Reading devices
- Gutenmakher, L. I. Director of Laboratory of Electromodeling. Electrical modeling of thought processes; automating information input
- Kholsheva, A. F. Reading devices
- Stretsiura, G. G. Reading devices

Mathematics Institute and Computer Center (Novosibirsk): self-teaching machines

- Kozhukin, G. I. Self-teaching machines

Mathematics Institute imeni Steklov:

- Kolmogorov, A. N. Parallel-operating automata; modeling thinking beings
- Lyapunov, A. A., editor, *Problemy Kibernetiki*. General cybernetics
- Lyubimskii, E. Z. Reading devices
- Ofman, Yurii. Parallel-operating automata

Mathematics Institute imeni Steklov, Leningrad Department:

- Varshavskii, V. I. Minimum description of images required for artificial recognition; pattern recognition with learning

Party Committee of the Presidium: Co-sponsored conference on "Philosophical Problems of Cybernetics"

Scientific Council on Cybernetics: general coordination of cybernetics research work; sponsored seminar on "Reading Devices"; co-sponsored conference on "Philosophical Problems of Cybernetics"

- Parin, V., Chairman of Section on "Cybernetics and Living Nature" (Bionics)
- Prokhorov, A.

Scientific Council on "Philosophical Problems of Natural Sciences": co-sponsored conference on "Philosophical Problems of Cybernetics"

Academy of Sciences, Latvian SSR

Institute of Electronics and Computer Technology:

- Dambitis, Ya. Ya. (probably). Self-organizing systems

Institute of Physics:

- Shneps, M. A. Self-organizing systems

Academy of Sciences, Ukraine SSR

Computer Center:

Glushkov, V. M. Machine intelligence; self-teaching/self-organizing systems; pattern recognition with learning; reading devices; recognition of meaningful sentences

Kovalevskii, V. A. Pattern recognition with learning; reading devices; automation of information input

Stognii, A. A. Recognition of meaningful sentences

Cybernetics Council: sponsored seminars on "Automation of Thinking Processes" and biocybernetics

Glushkov, V. M., Chairman of Cybernetics Council. Machine intelligence; self-teaching/self-organizing systems; pattern recognition with learning; reading devices; recognition of meaningful sentences

Stognii, A. A., Scientific Secretary of Cybernetics Council. Recognition of meaningful sentences

Institute of Cybernetics:

Gluskov, V. M. Director. Machine intelligence; self-teaching/self-organizing systems; pattern recognition with learning; reading devices; recognition of meaningful sentences

Institute of Electrical Engineering:

Ivakhnenko, A. G. Control theory in artificial intelligence; perceptron-type device

Mathematics Institute:

Amosov, N. M., Leader of Seminar on Biocybernetics

Kukhtenko, A. I. Self-organizing (control) systems

Other Institutes and Personnel Associated with Artificial-Intelligence

First Moscow Medical Institute, Department of Physiology:

Anokhin, P. K., Head of Department of Physiology. Physiology and cybernetics

Kazan Aviation Institute:

Borshche, V. B., published in *Trudy Kazan Aviatsionnyi Institut* (Works of the Kazan Aviation Institute). Machine intelligence

Il'in V. V., published in *Trudy Kazan Aviatsionnyi Institut*. Machine intelligence

Rokhlin, F. Z., published in *Trudy Kazan Aviatsionnyi Institut*. Machine intelligence

Kiev Computer Center:

Kondratov, A., associated with work at Kiev Computer Center; writer on artificial intelligence

Kiev Institute of Civil Air Fleet imeni Voroshilov:

Kukhtenko, A. I. Self-organizing (control) systems

Laboratory (now Institute) for Systems for Transmission of Information:

Blokh, E. L. Minimum description of images required for artificial recognition; "compactness hypothesis"

Garmash, V. A. Quasi-topological approach to recognition; reading devices

Kharkevich, A. A. Minimum description of images required for artificial recognition

Kirillov, N. Ye. Automatic discrimination of speech sounds

Pereverzev-Orlov, V. S. (probably). Quasi-topological approach to recognition; reading devices

Tsirlin, V. M. Quasi-topological approach to recognition; reading devices

Latvian State University, Computer Center:

Arin', E. I. Self-teaching machines

Leningrad State University, Experimental Laboratory of Machine Translation:

Andreev, N. D. Reading devices

Military Air Engineering Academy imeni Zhukovskiy:

Chinayev, P. I. Self-teaching/self-organizing systems

Moscow Power Engineering Institute: brain modeling

Kushelev, Yu. N., Engineer. Neurocybernetics

Krug, G. K. Self-teaching machines

Letskii, E. L. Self-teaching machines; neurocybernetics

Svechinskii, V. B., student. Neurocybernetics, modeling thought processes

Moscow State University: site of continuing Cybernetics Seminar

Leont'ev, A. N. Information processing in man

Lyapunov, A. A., coordinator of Cybernetics Seminars. General cybernetics

Moscow State University, Department of Higher Nervous Activity:

Chichvarina, N. A. Algorithms of conditioned reflex development; neurocybernetics

Napalkov, A. V. Algorithms of conditioned reflex development; neurocybernetics; self-organizing systems

Semenova, T. P. Algorithms of conditioned reflex development; neurocybernetics

Shtil'man, Ye. V. Modeling instruction processes using psychological learning theory

Sokolov, Ye. N. Modeling perception

Turov, A. F. Algorithms of conditioned reflex development; neurocybernetics

Voloshinova, Ye. V. Algorithms of conditioned reflex development; neurocybernetics; modeling instruction processes using psychological learning theory

Order of Lenin Institute of Power:

Fel'dbaum, A. I., Faculty of Automation and Computer Technology. Machine intelligence

University imeni Palacki, Olomuc, Czechoslovakia, Chair of Psychology:

Golas, E. Generalization in pattern recognition and learning

Osladilova, D. Generalization in pattern recognition and learning

Valousek, C. Generalization in pattern recognition and learning

Zaporozhe Oblast Psychiatric Hospital:

Gasul', Ya. R. Modeling thought processes

Additional Personnel Associated with Artificial-Intelligence

Biryukov, B. V., contributor to *Problem Kirbernetiki*

Blinkov, S. M. Structure of the brain

Fain, V. S. Minimum description of images required for artificial recognition; learning systems for recognition; automating information input

Fatkin, L. V., contributor to *Voprosy Psikhologii* (Questions of Psychology). Philosophical problems of cybernetics; automatic discrimination of speech sounds

Gutchin, Izrail', contributor to *Zarya Vostoka* (Dawn of the East), Tbilisi, Georgian SSR

Kamynin, S. S. Reading devices

Krisilov, A. D. Reading devices

Kubilyus, I., Prof., contributor to *Kommunist* (Vil'nyus). General cybernetics

Mayzel', N. I., contributor to *Voprosy Psikhologgi* (Questions of Psychology); philosophical problems of cybernetics

Mitulinskii, Yu. T. Minimum description of images required for artificial recognition

Petrenko, A. I., contributor to *Izvestiya Vuz* (News of Higher Educational Institutions). Reading devices

Poliakov, V. G., contributor to *Izvestiya AN SSSR* (News of the Academy of Sciences, USSR). Reading devices

Rozhanskaya, E. V. Mathematical theory of intelligibility (recognition)

Rybak, V. I. (probably Computer Center AS, UkSSR). Pattern recognition with learning

Saenko, G. I., editor of VINITI publication. Reading devices

Saparina, Ye. Brain modeling

Semenova, T. N. Pattern recognition with learning

Sindilevich, L. M., editor of VINITI publication. Reading devices

Sokolovskii, V. A. Minimum description of images required for artificial recognition

Svechnikov, S. V., contributor to *Izvestiya VUZ* (News of Higher Educational Institutions). Reading devices

Tarakanov, V. V. Perceptual activity in man

Tiukhtin, V. S. Theory of Images (and Perception)

Tsemel', G. I. Automatic discrimination of speech sounds

Vasil'ev, A. M., editor of VINITI publication. Reading devices

Vitushkin, A. G. Reading devices

Wang, Chih-ch'ing. Perceptual activity in man

Yeliseyev, V. K. Modeling recognition process

Zinchenko, V. P. Perceptual activity in man

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   Kolmogorov, A. N. "Life and Thinking from the Point of View of Cybernetics"

   Lyapunov, A. A. "On Control Systems in Living Nature and General Understanding of Living Processes"

   Glushkov, V. M. "Thinking and Cybernetics"

   Novik, I. B. "On the Nature of Information and the Peculiarities of Cybernetic Modeling"

   Fel'dbaum, A. I. "Instruction Processes for People and for Automata"
5. Mayzel', N. I. and L. V. Fatkin. "Conference on Philosophical Problems of Cybernetics," *Voprosy Psikhologii* (Questions of Psychology), Moscow, no 5, 1962 (JPRS: 17,574, 12 Feb 63)
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