Soviet Cybernetics and Computer Sciences, 1960

By EDWARD A. FEIGENBAUM

This article records observations on Soviet research and technology in cybernetics and computer science, made by the author during a visit to the Soviet Union as a delegate to the IFAC Congress on Automatic Control held in Moscow in the summer of 1960.

Introduction

The author visited the Soviet Union in June and July, 1960 to attend the First Congress of the International Federation of Automatic Control (IFAC) as an official American delegate and to meet with certain scientists in psychology, physiology, and the computer sciences, as well as visit some Russian research institutions doing work in these areas. In this article Soviet research in cybernetics, neurocybernetics, artificial intelligence, mechanical translation, and automatic programming is discussed and new developments in Soviet computing machines are described.

The author presents his discussions with several important Soviet personalities in the computer sciences, which dealt with their particular work and the work of their research institutions. He concludes that Soviet research in the computer sciences lags behind Western developments, but that the gap is neither large nor based on a lack of understanding of fundamental principles. He believes that the Soviets will move ahead rapidly if and when priority, in terms of accessibility to computing machines, is given to their research.

First International Congress of the International Federation of Automatic Control, Moscow, June 27–July 7, 1960

One of the purposes of my visit to Moscow was to attend, as an American delegate, this first congress of the IFAC.

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Plan of the Congress. The activities of the congress were organized in three cities: Moscow, Kiev, and Leningrad.[1] The actual working sessions of the congress were held at Moscow State University during the week of June 27–July 2. The sessions in the other cities, July 3–7, consisted only of technical excursions to industries and research institutions.

In Moscow, the congress scheduled two plenary sessions (opening and closing) and numerous daily technical sessions. Run in parallel with these business sessions was a rather large number of organized technical excursions to various industries and institutes. Also scheduled in parallel were many organized sightseeing excursions of the ordinary tourist variety. An active and highly organized Ladies' Program ran for the full week. The delegate was inundated by a blitz of organized activity.

First Plenary Session. The first plenary session of the congress, held in the Congress Hall of the university, was heavily attended. The program consisted of a number of welcoming speeches, and an address by the well-known scientist and Chairman of the USSR National Committee for Automatic Control, V. A. Trapeznikov.[2] The Communist welcoming speeches were heavily loaded with propaganda and exhibited what Western delegates thought to be an embarrassing lack of discretion, taste, and dignity. The Soviet Deputy Premier talked on the problems which automation would bring to "certain societies" which were not well equipped to handle this kind of technological change—change which would bring unemployment, re-education problems, and relocation stresses.

Technical Sessions. The technical business of the conference was divided into four major classifications: theory, components, industrial applications, and general problems. These classifications were further divided into twenty-one categories; categories are listed in Appendix B. Sessions in the various categories were run in parallel, though not every category held sessions every day. The number of papers given during the technical sessions was enormous: nearly 300 papers were presented in the five days of technical sessions. Almost all of these papers were available in preprinted form a few weeks before the conference. In no instance was I aware of the presentation differing in any way from the preprint.

The presentations were handicapped by translation difficulties. No simultaneous translation was available. Translations were, instead, sentence-by-sentence and often in more than one language.

The post-presentation discussions in the sessions I attended were generally uninteresting, uninformative, and tedious. Again, severe translation problems marred performance. Tedium was enhanced by the peculiar Russian habit of "discussing" a paper by delivering a 15–30 minute extension, clarification, or rebuttal of the paper.

In general, Soviet papers could be characterized as oriented toward theory, while papers of Western delegates mixed theory and application.

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[1] The Russians regarded the choice of Moscow for the first congress of IFAC as a feather in their caps, and used this opportunity for propaganda effect in the Soviet and foreign press. A special commemorative stamp of the event was issued; special commemorative "first day cover" envelopes were printed; the opening plenary session was addressed by a Soviet Deputy Premier; and a remarkably sumptuous and ceremonial reception for all delegates and their wives was held on the final day in the Czar's Palace in the Kremlin. Aside from this reception, however, there seemed to be no extra effort made to accommodate these "special guests" of the Soviet Union, and, in fact, the bitterness felt by many of the delegates because of the difficulties and indignities suffered during the conference was not mollified by the splendid Kremlin party.

[2] This speech was a highly significant statement of Soviet attitudes and goals in cybernetics and automatic control. Unfortunately, the speech received little attention and distribution. It was not available in the preprints of the IFAC Conference, and only a few printed English translations were distributed after the session. I am sure, however, that the speech will appear in the final conference volume when it is published.

Technical Excursions. In conjunction with the conference, various research institutes, educational institutions, and plants were officially opened for technical excursions by the delegates. These excursions are listed in Appendix C. The trips were highly organized affairs and consisted of about 60 people each. By far, the most popular tour was one to the Institute of Automation and Telemechanics in Moscow.

These were canned, planned tours, and provided no opportunity for personal contacts or detailed questions. To my way of thinking, they were a severe time-wasting activity, using up the few hours available for personal contacts in Moscow. After speaking with other delegates who took these trips, I am convinced that this judgment is correct.[3]

Person-to-Person Communication. The greatest value of most large conferences lies not in the transaction of formal business, but in the informal exchange of ideas and information among delegates, who should be given ample opportunity to meet and converse.

Interpersonal communication between Western and Soviet delegates was held to a minimum. All foreign delegates were boarded in the enormous Hotel Ukraine, on the outskirts of the Moscow central area; Soviet delegates were housed in a number of different hotels in the center of Moscow. It was not possible to officially obtain names of the hotels of Soviet delegates, or knowing the hotel's name to obtain from the hotel desk the delegates room number or telephone number. The only list of the delegates and their hotel locations which I saw was one printed by the American delegation listing data on American delegates.

There were no official communication channels between delegates, no central communications center for the delegates, no message system, no mailboxes. It was relatively easy to contact any foreign delegate through the desk at the Hotel Ukraine, but it was almost impossible to contact a Russian delegate.

Soviet delegates could be met by seeking them out at the conference. This was a hit-or-miss procedure with a small probability of success. The various parallel sessions were taking place in widely separated areas of the university. Furthermore, the technical sessions were not well attended by Russians, or by foreigners. Most frustrating of all, the Soviet delegates did not, in general, wear the big name tags provided for delegates, though virtually every Westerner wore his continuously.

Sidelights on IFAC. In reception and handling, difficulties and indignities suffered by the delegates at the hands of an inept staff were marked. Travel arrangements to conference cities and other places were handled with incredible inefficiency.

The delegates arrived in Moscow on Saturday and Sunday. The Soviet passport-checking procedure at the airport broke down in the face of the onslaught of delegates and wives. Transportation arrangements for taking delegates to the Hotel Ukraine were chaotic. At the hotel, delegates were faced with a waiting line of a hundred or more at the Intourist Bureau, where hotel rooms and food coupons were being distributed.

The conference moved from Moscow to Kiev and Leningrad on July 3. Over one thousand foreigners had to be moved to these and other cities. During the conference week, inquiries about tickets elicited the following standard reply, "What are you worrying about? It's too early. You're not leaving until Sunday. All tickets will be handed out at noon on Saturday." There were no tickets at noon on Saturday, nor at three, six, nine, and midnight. By mid-evening the Intourist Bureau was crowded with worried, tired delegates queueing up for tickets. After midnight, a list of names and room numbers was drawn up with instructions to Intourist to phone these people when their tickets arrived. Disgusted, I went to bed about 1:30 AM, after signing the list. I was not phoned. I understand that others were, and that they stood in queues at all hours of the night. I did not get my tickets and thereby missed the 9 AM flight to Tbilisi. Sunday afternoon, having uncovered the fact that there was a plane to Tbilisi at 6:00 PM, I made a plea of desperation to one of the Intourist girls to issue me tickets for this flight. With an air of surprise which seemed to say, "How could you get so worked up over such a minor thing," she issued the tickets and travel coupons in less than five minutes!

Rumors flew all week that the delegates were to be invited to a reception at the Kremlin on Saturday. In typical Russian fashion, no invitations went out and no official announcement was made until the final plenary session of the congress a few hours before the reception. The party, given by the Academy of Sciences of the Soviet Union, was held on the Kremlin grounds, in the Czar's Palace—a building which is the seat of the Soviet Presidium and is generally closed to visitors. It was a splendid reception, highlighted by culinary luxuries and excellent entertainment—a dizzying performance by our inconsistent Soviet hosts.

Evaluation. In my opinion, the primary value of this conference was that it provided an opportunity for 135 Americans and many other Westerners to visit the Soviet Union and gain a first-hand impression of Soviet society today. It also gave a limited number of Soviet citizens a chance to meet, talk with, and evaluate these several hundred Westerners. Here I wish to emphasize person-to-person mutual enlightenment, rather than scientific and professional exchange. In these turbulent times of uncertainty and mutual distrust, we cannot have too much of this. If conferences can provide a way of channeling corporate, private, and governmental funds for this important educational endeavor, I believe their worth to be established.

From the viewpoint of mutual exchange of scientific information, the IFAC congress made a rather poor showing. Most large conferences are bad in this respect, but something useful is salvaged when delegates meet and talk informally. Because of the severe constraints which limited the contact of Westerners with Russians,

[3] There was an exception. Nelson Blachman, of Sylvania Electric Products Company, Mountain View, California, saw a transistorized digital computer at the Moscow Power Institute. His report on this computer may be found in ONR Technical Report ONRL-C-15-60, Sept. 9, 1960, and in the *Communications of the ACM*, June 1961. As far as I know, this is the only American report of this machine. The computer has the following characteristics: speed—25,000 fixed-point operations/sec, or 5000–7000 floating-point operations/sec; word length—20 or 40 bits; memory size—4096 words of ferrite core, fixed store of 256 words on condenser-printed paper, magnetic-tape store of 50,000 words; output—numeric only; clock speed—100kc. Blachman reports that this computer was built by students in three years, beginning in 1957.

the IFAC congress could not claim even this salvage value.

The Private Business of One Delegate in Moscow

PROBLEMS OF THE IFAC DELEGATE. In planning my trip I thought that as a delegate to a distinguished conference I would have the kind of "important guest" status that would open doors and ease my job in making personal contacts. This is not what transpired. The fact is that most IFAC delegates were patently refused admittance, sometimes more subtly than at other times, to those institutions which were not included in the schedule of technical excursions. No amount of taxicab riding, telephoning, insisting or cajoling could open these closed doors. The number of individual incidents which stand as evidence of this policy is formidable.

My interpretation is that the Russians, faced with the overwhelming problem of controlling the movements of several hundred highly intelligent scientific people, settled on a policy of closing all scientific doors even remotely related to the interests of these people, except those doors which were officially opened as part of the conference. I suspect this policy held in the other two conference cities as well, for I experienced great difficulty in making personal contacts in Kiev and Leningrad, even with people who were expecting me, and even though I arrived in these cities after the rest of the conference had departed.

Examples of my difficulty will come up in the various sections of this report. Perhaps the best example of what was going on in Moscow at the time is one which did not affect me very much. To my knowledge, no delegate gained admittance to Lebedev's Institute of Precise Mechanics and Computing Techniques. Even those who carried written invitations from Lebedev himself, as a result of his trips to the U.S.A., England, and West Germany, were denied entrance. One persistent English fellow was forcibly turned away at the gate. This is especially surprising since Lebedev's Institute has had more-than-usual contact with Western delegations. To sum up, things were bad enough for an American in Moscow in June, 1960; being a delegate to the IFAC congress only made things worse.

A. P. YERSHOV. I visited with Dr. A. P. Yershov, Director of Theoretical Programming at the Computing Center of the Academy of Sciences of the U.S.S.R., who is a major force in automatic programming in Russia. His magnus opus, *Programming Program for the BESM Computer*, has been published by the Pergamon Press in an English edition. Dr. Yershov has moved to Novosibirsk to take up a major post as head of programming research in this new scientific complex.[4]

Dr. Yershov is a man of great intelligence, curiosity, energy, and he has considerable awareness of the state of the computing art in Russia as well as in the United States. In Novosibirsk, he will have influence, and, I believe, relatively great freedom, and most important, a good, modern computing machine (or machines!).

The following notes briefly summarize our talks:

1. *Activity in Novosibirsk.* Dr. Yershov's new position in Novosibirsk was a focus of our conversation. An M-20 computer had already been installed in Novosibirsk, and had almost been debugged.[5]

Dr. Yershov was working on an ALGOL-type language, since completed at Novosibirsk, for the M-20. At the time, he had a staff working with him at the computer center in Moscow on this project.

In Moscow, programming research people do not influence the design of new machines, which is strongly under the control of Lebedev's Institute of Precise Mechanics and Computer Techniques. In Novosibirsk, however, Dr. Yershov and his colleagues hope to do extensive computer development, in which the various "disciplines" in the computer field will cooperate. This cooperation, he insists, is a necessity.

Once established in Novosibirsk, Yershov hopes to begin work as soon as possible on the so-called "logical languages," especially symbol-manipulating list-processing languages whose development, he says, is now essential. He knows of the U. S. list languages called IPL and LISP.

2. *Activity in Moscow.* One would expect automatic programming languages to be widely used in Yershov's own shop; but, this is not the case. Yershov said that only a very small percentage of all problems done at the Computing Center are run with the aid of a Programming Program. He gave two reasons: first, and most important, the lack of alphabetic input-output devices; second, the reluctance of the experienced programmers to learn a new system and switch over to its use.

According to Yershov, the computing center of Moscow State University is concerned with the solution of practical scientific and engineering problems. No basic computer research is being carried on there, and there is no interest in the theory of programming.

A. A. Lyapunov is, of course, at Moscow State University. Lyapunov is the Norbert Wiener of Russian cybernetics, a world-famous mathematician, and a revered man in Soviet scientific circles. As the patriarch of cybernetics, he helps to organize and transmit knowledge in the field. He is responsible for bringing about various cybernetics conferences in Russia; he began, and continues to edit, the well-known volumes, *Problems in Cybernetics*; he continues to teach at the University; and he personally looks after the education of a number of promising graduate students. He recently organized a volume of articles translated from our journals and publications, on the STRETCH computer.

L. I. GUTENMAKHER. I spoke with Professor L. I. Gutenmakher, Director

[4] His new address is: Siberian Division, Academy of Sciences of the U.S.S.R., Institute of Mathematics, Novosibirsk 72, U.S.S.R.

[5] The M-20 is one of the latest of the large Soviet machines. Some data on the M-20 follows: mode, 3-address floating-point; average number of operations per second, 20,000 (Soviet estimate, using statistical mox of instructions based on normal use); additions per second, 50,000; multiplications per second, 17,000; word size, 45 bits; core store, 4096 words; complete memory cycle time, 6 microseconds; drums, three units with a total of 12,000 words and a transfer rate of 12,000 words per second; tapes, four units, each eight channel, addressable blocks of 1–4000 words, transfer rate of 2500 words per second; input-output, punched cards and on-line printer; alphanumeric capability, unknown, but probably absent. For information on other Soviet machines, see: Ware, W., ed., "Soviet Computer Technology—1959," Transactions of the Professional Group on Electronic Computers, Institute of Radio Engineers, March, 1960. Also published as a RAND Corporation Research Memorandum, RM-2541, March 1, 1960.

of the Laboratory for Electrical Modeling of the Institute of Scientific Information. Despite rumors to the contrary—as far as I can determine—this laboratory is still part of the institute. The institute, I gather, employs about 300–500 people. Gutenmakher himself is a well-known figure both inside and outside the Soviet Union. His early work was with analog computers. In 1949, he published a book titled *Electrical Models*, which dealt with electrical analog models of physical systems. His recent work has included some flamboyant and speculative material on the simulation of human brain functions, and on intelligent information retrieval machines operating with the principles of human associative memory. Gutenmakher's writings on the automation of brain functions are provoking. His ideas on associative memories for computers are, in general terms, quite close to those of the RAND-Carnegie Tech Simulation of Cognitive Processes research effort. This year, a book of his was published, *Electronic Informational-Logical Machines*, which sold very well in Moscow. He is an uncommunicative man and rather unfriendly, and he has a reputation for being a difficult man to get to meet.

We spoke in German about the work of his laboratory. They are engaged in building a so-called information machine, and he referred me to his recent book for more information on the subject. The book, incidentally, gives a "popular" rather than a technical treatment. I inferred that the machine is more of a digital information processor than a digital computer. That is, it is being designed specifically for the problems of information storage, retrieval, and manipulation, rather than for purposes of calculation. When I questioned Yershov about this machine, he told me it was an "ordinary" type of digital computer, but Gutenmakher contradicted this, claiming that it was not the "ordinary" type but that it had an associative memory. I believe the resolution to this contradiction is that the machine utilizes familiar components in a novel design for information processing. Many of his workers are engaged in constructing this information machine.

Professor Gutenmakher said he has a large group working on the problems of: (a) information retrieval of chemical data and (b) mechanical translation of languages. Dr. Yershov had told me that the laboratory was also working on an "information language." He said that this is *not* a programming language. My impression is that it is a language convenient for coding textual materials and data. The chemical information previously mentioned will be or already has been coded in this language. He mentioned that the mechanical translation group is also very interested in using the language, so it is likely that the language has some rather general properties. He mentioned that a brief account of this language is presented in his new book.

I questioned Professor Gutenmakher about the laboratory. In the course of speaking of the laboratory's work, he mentioned that there was so much to do, and so little time in which to do all that needed to be done. I asked him how many people worked in the laboratory. "Enough," was his answer. I asked him for an order of magnitude. "Large," he answered. His researchers (as opposed to laboratory technicians) are mathematicians, logicians, linguists, engineers, and physicists. He said that there were no psychologists and no physiologists. They were not experimenting on human memory, nor were they experimenting in the area of higher mental activity in connection with simulation of brain functions.

In connection with theorem-proving machine, he has some people working on a geometry machine. He did not know of Gelernter's work on a geometry theory machine.

The Laboratory had no game-playing programs.

On the topic of the simulation of mental activities of the brain, his comments were significant. He believes a machine will imitate these activities. I asked him how long he thought this would take: 50 years? 20 years? No, he said, this was too long. So I told him of the estimates given by Newell and Simon three years ago that a machine would be a chess champion in ten years and would discover and prove an interesting new mathematical theorem in the next ten years. Gutenmakher said that this was a much better estimate, but that it was too conservative. He felt that this sort of thing would happen in less time.

A. V. Napalkov. A. V. Napalkov appears on various published papers as an associate of Professor S. N. Braines of the Laboratory for Physiological Research of the Institute of Experimental Psychiatry. He is also on the Faculty of Higher Nervous Activity, Moscow State University.

Napalkov is a physiologist whose basic interest is in machine models of physiological (and psychological) processes.[6] He teaches at the university and does his work there in conjunction with Braines' Laboratory with a staff of young assistants, some of whom are graduate students. His laboratory, which is in the new building of the Biological-Soil Faculty, is modern and impressively well equipped.

Braines and Napalkov have built a conditioned-reflex learning machine. At the laboratory, they also have a chimpanzee or two with which they perform complex conditioning experiments. The laboratory is reported to have carried out the much-publicized experiments with dogs on restoration of youth through long sleep.

Napalkov and I exchanged ideas about brain models. His research method is substantially the same as that of the RAND-Carnegie group: make observations of behavior (of humans and/or animals) in complex environments; construct machine models of the behaving organisms based upon knowledge of what some plausible mechanisms might be; allow the machines to behave in simulated environments; compare the behavior of the machine-model with the observed behavior.

Following our discussion, his assistants ran off an experiment in complex conditioning with a dog in which a chain of conditioned responses was interposed in another chain of conditioned responses. The experiment was designed to show that a dog could learn this kind of cycle-within-a-cycle behavior.

Studies of the chaining of responses are typical of the work of Napalkov and Braines. An animal is trained to press a key for some reward. The key-pressing is then reinforced only when a tone is sounded, which occurs only if the animal has previously pressed a certain lever, and so forth. Many variants of

[6] For discussion of Napalkov's work, see: Herbert Pick, "Some Current Trends in Experimental Psychology in the Soviet Union," 1960, University of Wisconsin (Psychology Department), Unpublished Ditto.

the basic experiment have been performed in which: (a) the timing and nature of the chain-stimuli have been varied, and (b) conditions external to the chain (e.g. hunger, thirst) have been varied. In one interesting experiment, two different chains leading to different kinds of rewards (food in one case, water in the other) were taught to rats and dogs. The chains had a common link. The animal was then deprived of, say, food, and subsequently run in the water-chain. The problem under investigation was whether or not the animal would switch at the common link into the other chain (in this case the food chain). Experiments like these provide the behavioral data from which Napalkov, Braines, and their engineers attempt to build machine-models of animal behavior.

Napalkov told of having to write many general and "popular" articles about his brain-model research, as well as numerous official memos, to convince people with authority that his research should be supported. He said that there was much opposition among physiologists to the machine-modeling approach.

Some of the theoretical basis for the Braines-Napalkov learning machine may be found in a small book of working papers written by Braines, Napalkov, and Svechinskiy. The book is entitled *Scientific Notes (Problems of Neurocybernetics)*, published in Moscow, 1959.[7]

A. R. Luria; The Institute of Psychology. I called upon Professor Luria of the Psychology Department of Moscow State University and the Institute of Defectology. Professor Luria is a distinguished scholar, well known in the West, who speaks perfect English, and has visited and lectured in both England and America. Luria's book, *The Role of Speech in the Regulation of Normal and Abnormal Behavior*, has been published in English.[8]

Luria spoke briefly of his recent work on the influence of language on the initiation and regulation of simple motor and verbal behavior in children. This work is adequately summarized in Herbert Pick's report, to which the interested reader is referred.[9]

During our conversation, he noted that Dr. Eugene Sokolov of the Faculty of Higher Nervous Activity at the university was interested in modeling mental processes on a computer.[10]

Luria asked me to talk to the psychologists at the Institute of Psychology about my research.[11] This I subsequently did. The talk was attended by about fifty people, many of them young. Dr. Smirnov, head of the Institute of Psychology, chaired the question period. The session was marked by intelligent questions showing an understanding of what I had been saying about computer models of learning. Dr. Smirnov himself has done research on human memory, and has written a book on retroactive inhibition.

After my lecture, I had a long talk with a young researcher. It was one of those random meetings which pays dividends. She works at the Institute of Foreign Languages in the Experimental Laboratory for Phonetics where she does research on speech perception. She is now concerned with the relationship between perceptual processes and memory. She believes that the study of human perception of speech will aid in the solution of some fundamental problems in mechanical translation of languages, e.g. the problem of groupings of words, and the problem of selection from a set of alternate meanings.

The Laboratory for Phonetics is interested in building a speech-recognition machine, but at present they have no electronics lab of their own. Furthermore, they do not have access to a computer. She told me that the Department of Mechanical Translation of the Institute of Foreign Languages has requested their own computer, but their request has so far been turned down, and she thinks they will not get the machine.

A Lecture by Norbert Wiener. On June 28, Norbert Wiener lectured to the Russians at the Polytechnic Museum in downtown Moscow. He spoke on the analysis of brain waves and on some results of his electro-encephalographic research. Attendance turned out to be standing room only; 500–700 people were present and many were turned away. Most of the questions in the question period were concerned with the comparison between brains and machines. It was obviously a topic of much concern to the Russian scientists. The most vigorous applause of the evening came when, in answer to a direct question, Wiener stated his belief that the creativity of man would always find a higher level than the creativity of a machine. The Russians were clearly gratified by this answer.

The Business of One Tourist in Tbilisi, Capital of the Georgian Republic

Computing Center, Academy of Sciences of the Georgian Republic. Contrary to my experiences in Moscow, I had no trouble with my appointments in Tbilisi. One call to the computing center sufficed to bring someone quickly over to my hotel. Professor Kueselava, who is Director of the Computing Center of the Academy of Sciences of the Georgian Republic and a professor of mathematics, and part of his staff greeted me on arrival. He said that he received my letter and was glad I was able to come.

The center is currently housed in a poor building in an old, but central, section of Tbilisi. A new building is currently under construction but is in a more outlying area. The center in Tbilisi is a relatively recent phenomenon. It was opened in 1958, and staffed by mathematicians, scientists, and engineers drawn from the local university and polytechnic institute. These people were trained in computing in Moscow (two to three years of training). The center now employs two hundred people, many of whom are technicians and engineers.

The center operates a Ural Computer (Serial No. 78), which is installed in a rather sloppy fashion in a large, undignified room in the half-finished new

[7] This book has been translated into English by the Joint Publications Research Service as **JPRS** 5880, October 18, 1960, and is available from the Office of Technical Services, Department of Commerce, Washington 25, D. C. $3.50.

[8] A. R. Luria, *The Role of Speech in the Regulation of Normal and Abnormal Behavior*. Pergamon Press, London, 1961.

[9] Pick, *op cit*.

[10] Some very interesting and informative notes on the work of Sokolov are to be found in the paper by Herbert Pick, *ibid*. See also: E. N. Sokolov, "A Probability Model of Perceptron," *Voprocii Psichologii 2*, (1960) (journal available in English translation by Pergamon Press).

[11] For a discussion of the work of the institute, see: W. Reitman, "Some Soviet Investigations of Thinking and Problem Solving," unpublished manuscript, Carnegie Institute of Technology, Pittsburgh, Pennsylvania (forthcoming in a published collection).

building. Down the hall, in an unfinished room, the Besm II was being assembled. The various functional units (adder, memory, frame, etc.) were sent down individually from Moscow and assembled into a machine by the center's Moscow-trained engineers. They estimated that the machine would be completed by about January-February, 1961. As far as they know, there is no factory that turns out complete Besm II machines. They are probably right. In Latvia, where a Besm II is currently being installed, it was being built in just the same way as the machine in Tbilisi.

The center is young, and still feeling its way, trying to become established. As effective computer installations go, this center is still in a rather primitive stage. Their Ural computer is slow: its output is on the narrow tape of a 10 (or possibly 14) digit/line "adding machine"; its input was by punched 35mm film. I was peppered with questions about the reliability of U. S. computers. The implication was that the Ural had low reliability.

Concerning programming, they work mostly on practical problems, but some research in automatic programming and mechanical translation has been undertaken. Currently, they were engaged in writing special subroutines for Ural (and, I presume, Besm-II) in connection with problems in physics. In fact, their main interest at the moment is with the solution of physics problems, and they work closely with the Research Institute of Physics on these problems.

The mathematicians at the center are working on boundary value problems, eigenvalue problems, evaluation of integrals, and solution of differential equations.

They told me that they have dedeveloped a programming program modeled after Yershov's program. I told them I was interested in understanding this system, and would like to write a program in it. They wanted me, instead, to write my program in Ural machine code, but I declined. However, it developed that their programming program existed on paper only, and was not really a working compiler. The reasons for not developing it further were: (a) that Ural is too small and slow to accept a decent compiler; and (b) that experienced programmers wouldn't use it. Sometime next year they expect to begin their machine translation program in earnest although some of their staff is already working on it. The Institute for Automatics and Telemechanics in Tbilisi is already working on translations of Russian into Georgian, and the people in the center hope to do some joint work with the institute.

These people are isolated from the computer-world of the West. My impression was that they do not know of our computer journals, our automatic programming efforts, our artificial intelligence studies, etc., and they have only the sketchiest information about our machines. Many of the questions they put to me were about our computers. For example, they asked about the characteristics of the machine that plays chess (i.e. the Newell-Shaw-Simon chess program). In answer, I reported the general characteristics of Johnniac (an antediluvian machine by 1960 American standards). They were particularly impressed when I referred to Johnniac as an "old machine." They plainly did not believe me when told the memory size of some of our commercial computers.

The computing center at Tbilisi services the Georgian Republic. They told me that industry does not have its own machines, nor does the university. All problems are brought to the Computing Center of the Academy of Sciences where these problems are handled by the center on a closed-shop basis.

One of the most interesting conversations I had at the center concerned the nature of control of research activity in the United States. We first discussed the chess machine.

"What is the practical use of such a machine?" they asked.

I replied that there was no immediate practical use for such a machine; that the people who undertook this project wished to study the nature of the problem-solving process in human beings and for computers.

"But who allows you to do this?" they asked. "Who tells you that you can do such research?"

In my reply I tried to explain to them the nature of research done at universities—that problems are undertaken by faculty members because these faculty members are stimulated by the topics, not because the research is necessarily oriented toward any kind of practical solution of a problem.

"But who allows you to do it?" they continued. "Who gives you the money? Where do you get the computers?"

I explained to them that the universities sponsored some research and that, in some cases, universities had computers of their own which they made available to faculty research.

I also explained to them the "foundation" system for sponsoring research. I told them about the Ford Foundation, the National Science Foundation, and other foundations, and explained to them how people who want to do research get grants from these foundations.

They were amazed and very impressed. They had no idea, they said, that such institutions existed. They thought this system was a very good idea.

In my conversations with them I had told them of the geometry machine done by Gerlernter at the IBM Research Center. They questioned me further about this. They understood, they said, that American companies were profit-motivated. How was it then that a big American company would sponsor such impractical research as a geometry-proving machine? Was not research on thinking machines and learning machines impractical? I tried to explain to them that although the big companies are in fact motivated by profit, basic research is good business, because out of this year's basic research, next year's good ideas spring. They nodded their heads. Yes, this was true. They understood.

They also asked me about the National Physical Laboratory in England where I spent the 1959–60 academic year on a Fulbright Grant. I told them about government-sponsored research laboratories in America and England. They were impressed, and said they did not realize there were such government-sponsored institutions in England and America.

It was obvious to me that these people were highly constrained in their choice of research problems, selecting only those which were important and practical, rather than those which were merely interesting from the point of view of their own curiosity. If they were to work on advanced problems of computer applications, they would do so because the signal had come from Moscow that they could or should work on these problems. This provided a most interesting insight for me on how things get done in Soviet science.

INSTITUTE OF ELECTRONICS, AUTOMATICS, AND TELEMECHANICS. I had not planned to visit this institute, yet I encountered no difficulty in arranging a visit at a moment's notice. The Institute of Electronics, Automatics, and Telemechanics of the Georgian Academy of Sciences, is within short walking distance of the Hotel Intourist. The institute is three years old and employs two hundred people: engineers, physicists, mathematicians, linguists, and technicians. There are five divisions within the institute: electronics; automatics; telemechanics; control of industrial processes; and mechanical translation of languages. The largest of these is the division for the control of industrial processes. Examples of its work include development of certain tooling processes with lathes, and control of industrial metallurgical processes (e.g. the rolling of steel).

The division I was most interested in was mechanical translation, the smallest of the groups, but I was not able to contact anyone from this group. I do know, however, that there are six people working on Russian-to-Georgian translation algorithms at the institute, and that, in addition, there are some mathematical linguists working on studies in logical and statistical analysis of Russian and Georgian languages as an aid to the translation work.

The electronics division is currently doing some experimental work with digital equipment using vacuum tube technology, though they are beginning some work with transistors.

The automatics division is largely concerned with analog machines for regulation in specific practical applications. (An example cited to me was autopilots.) They seemed to be little interested in the theory of controllers, theory of automata, or general cybernetic theory. However, a paper describing research on control using homeostat-like devices was presented by the vice-director of the institute, Chichinadzye, at the IFAC meeting, and is available in the pre-prints.

A point to note, and one of possible interest to students of Soviet scientific organization, is the apparent duplication of effort on mechanical translation in Tbilisi, a relatively small and provincial outpost of science. Some collaboration of effort is expected, but at present this is minimal. Why, then, are there two separate research teams within blocks of each other? Is this a reflection of a "decentralizing" philosophy in planning basic research in the computer area? Or is it an accident resulting from some peculiar decision-making channels in a complex and confused bureaucracy?

Trials of an Unwanted Guest in Yerevan, Capital of the Armenian Republic

S. N. MERGELYAN. Academician S. N. Mergelyan is the Director of the Scientific Research Institute of Mathematical Machines of the Armenian Academy of Sciences in Yerevan. He was a member of the Russian computer delegation that came to the United States in 1959. Mergelyan's Institute (as it is called in Yerevan) was then developing three new computers: ARAGATS, RAZDAN, and YEREVAN, which have subsequently been completed.

My attempts to visit Mergelyan's Institute were frustrating and met with eventual disappointment. After many telephone calls over a two-day period, I was told that I should stop bothering the institute with my telephone calls. They did not want to see me, and I could not come over, they said.

M. G. ZASLAVSKIY. I spoke with Mr. M. G. Zaslavskiy of the Physical-Mathematical Faculty of the University at Yerevan. Though he is on the faculty at the university, Zaslavskiy spends part of his time at the computing center. He is a mathematician who divides his effort between two kinds of studies: first, theory of functions and theory of algorithms; and, second, theory of finite automata. He said his goal was to develop a general theory of algorithms at the foundations of mathematics of which algorithms in the form of computer programs will turn out to be special cases. In connection with this goal, he wishes to study the link between the theory of algorithms and a general theory of computer programming.

Some recent work of his has been in the theory of constructive functions. He has also been engaged in research on algorithms to define the addition and multiplication operations in number systems more suitable to the representation of real numbers than present systems. All of this work is at the moment highly theoretical.

In the theory of automata, Zaslavskiy has been studying the kinds of descriptions which can be given to events, and how such descriptions can be represented in automata having various numbers of states. He ties this work to the work of Turing, Moore, and Glushkov. He stated that this work has just begun, and there are at present no results.

COMPUTING CENTER OF THE ARMENIAN ACADEMY OF SCIENCES. The computing center is physically located in a relatively new building in Yerevan. I learned from a taxi driver that the building is two or three years old. Later, some center personnel told me the center was only six months old.

In my visit, I was led directly to the office of the Director of the Computing Center. The director, Alexandreyan, was not present, but his assistant, Tsaakian, presided over the interview. The only other person present was B. M. Girgorian, head of the mechanical translation project at the computing center, who spoke very good English.

The Computing Center of the Armenian Academy of Sciences is organized into three divisions: (1) the Division of Theoretical Explorations, (2) the Division of Programming, and (3) the Division of Machine Translation of Languages.

The first division, the Division of Theoretical Explorations, is currently working on problems of differential equations, functional analysis, theory of algorithms, and problems in mathematical logic. The head of the computing center is also the head of this division. Zaslavskiy is affiliated with this division.

The second division, the Division of Programming, is concerned with the solution of practical programming problems. It seems that this division is not working on any advanced techniques, nor is it constructing any kind of automatic programming language.

The third division, the Division of Mechanical Translation, headed by Grigorian, is presently working on the problem of translating the Armenian language into an intermediate language, an artificial logical language. Grigorian, a philologist by training, also lectures at the university. His division consists of twelve people who work on a permanent basis, plus some interested people from the university; this division is gradually being enlarged. When I asked

Grigorian about the interest among philologists in mechanical translation, he told me that the course he offered in mechanical translation at the university last year was attended by about forty or fifty people. This figure might not be surprising for a university in Moscow, but in Yerevan it is an astounding figure.

I judge the program they have in mechanical translation is not far along. Under their translation scheme, a sentence is analyzed at three levels: first, graphical analysis of symbols; second, morphological analysis, and third, syntactical analysis. The end product of translation of a sentence from Armenian into the intermediate language is a string of numbers representing the words and their interconnections. After a word is located in the interlingual dictionary, its number is entered into the translation. If there are various meanings for a word, the conjunction of all various meaning-numbers is entered. So far, the resolution of multiple meanings is accomplished only by the use of grammatical clues.

Grigorian said he was writing an automatic programming language for mechanical translation. When I probed on this point, it turned out that the automatic programming language was really just a convenient set of subroutines for analyzing various features of sentences. Grigorian called these subroutines "operators." In the language there is a total of fourteen operators: some of these search for various features of sentences; one of them reduces disjunctions; another is for output; and so on. As far as I could determine, this language embodies no new ideas about memory structures for information processing.

In 1960, the center had only one computer, an M-3. I was told that they consider this machine much too small for their present purposes. An M-20 is on order from Moscow, and should be in Yerevan by the end of the year. Also on order, locally from Mergelyan's Institute, is an ARAGATS computer, but they were uncertain about the date of arrival of this computer.

Hasty Business in Kiev, Capital of the Ukrainian Republic

BACKGROUND. Kiev is touted as a major center for cybernetic research in the Soviet Union. Mentioned in various publications were the following research projects which were supposedly going on in Kiev: simulation of the higher nervous system, pattern recognition, the mathematical foundations of constructing machines for diagnosis of heart ailments, machine learning and nerve synthesis, programs for checking the validity of mathematical proofs, automatic machine make-up of train schedules, and so-called "economic cybernetics".

A cybernetics conference in Kiev in 1958 had set up an Institute of Higher Nervous Activity in Kiev under the direction of Professor Amosov. While in London I made the acquaintance of a travelling Russian by the name of Dr. Ivakhnenko, whose work in Kiev was in the field of "technical cybernetics," the theory of self-optimizing control systems. I was, therefore, most interested in exploring the status of research in these areas in Kiev.

By virtue of a scheduling decision, which in retrospect I consider to be ill-advised, I had scheduled a visit of only two days in Kiev. I arrived a day late in Kiev because of air travel difficulties. There had been some looseness in my schedule which I attempted to exchange for two extra days in Kiev. Unfortunately, Intourist would not allow it, and the whole of my Kiev activity was crowded into one day.

COMPUTING CENTER, UKRAINIAN ACADEMY OF SCIENCES. My call to the computing center brought a quick response, and I was immediately taken to the center by car. The center is located in a relatively new building in an outlying district of Kiev. I was greeted with warmth and enthusiasm by Dr. Glushkov, director of the center. Glushkov is a top theoretician, and spoke in some detail about his work. He spoke English haltingly, but seemed to understand everything I said.

The computing center has a so-called KIEV computer which was built by the center, but we spoke very little about it. We talked mainly about the research work of the center and the work of Glushkov himself. He is concerned primarily with problems of abstract automata. However, he has also been working (with graduate students) on the problem of teaching a machine to recognize a meaningful phrase.

A limited vocabulary, consisting of twenty nouns, fifteen verbs, and fifteen to twenty adverbs, is selected. Glushkov pointed out that once these words are chosen, it is possible to enumerate all sentences containing these words and then tell the machine which of these possible sentences are in fact meaningful. But because of the number of combinations, this is obviously the wrong way to approach the problem.

The goal is to expose some meaningful phrases to the machine, and, after certain processing, the machine will tell you whether or not a new phrase is meaningful. If the machine makes a mistake, it is told its last response was in error. The idea is to have the machine form classes from particular instances given to it. For example: suppose a class of "standing objects" is set up, for example: house, boy, man, child. When sentences with the verb "think" are given for the first time, the machine will correctly announce that "boy thinks," "man thinks," and "child thinks" are meaningful phrases, but will incorrectly announce that "house thinks" is a meaningful phrase. The machine will then start a new class for the variant item. That is, in this case, a class of objects which "stand but do not think." Admittedly, the proliferation of such classes may be quite large, but Glushkov maintains, much smaller than the set of sentences arrived at by enumeration. This class-splitting and building process is also carried out for non-verb-adverb sentences.

Another active research project at the Kiev Computing Center is pattern and character recognition. This research is accurately described in the report of the 1959 Computer Delegation.[12] The work has proceeded in two phases. The first phase, which is now complete, consists of a tracking program which scans letters and follows their edges. The essential principle is elegantly simple. A cathode-ray beam provides a light spot which is focussed through a lens onto the scanned letter. The light reflected from the letter is collected by a photomultiplier tube. The collected signal gives light-dark information. The beam moves with unit steps in small squares, clockwise in a white field and counterclockwise in a black field. This process is illustrated in Figure 1.

To prevent cycling of the beam in an all-white or all-black area, the tracking mechanism adjusts itself to move two units at a time when two successive

[12] Ware, W., ed., *op. cit.*

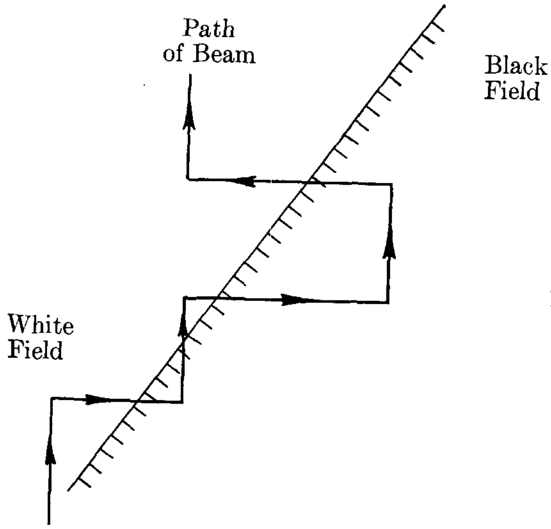

FIG. 1. Movement of beam in character recognition machine of Kiev Computing Center

unit moves have produced no change from white to black or black to white. This simple mechanism will result in a rough tracking of the edges of a letter.

At each point that the beam changes direction, a new average direction is computed and coded. In this coding, only eight directions are recognized: 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°. A recognition system based on this coding is, therefore, insensitive to slight rotational changes in the letters. Large rotations, however, cannot be tolerated. It was mentioned that this lack of discrimination is not a source of concern because "rotation of letters is never an allowable operation in ordinary printing and reading."

The second phase of the project is as yet unsolved. It concerns the problem of what to do with the codes that result from tracking a letter. Currently, the people at the computing center are gaining experience with the kinds of codes produced by the tracking system operating on real letters. They hope to find certain invariances among the codes taken from the same letter. What they are looking for is a set of good discriminators which will sort out the various letters, digits, and characters. This effort as yet has not been successful, and they suggested that they need a great deal more experimentation with the system.

CONCLUDING NOTES. The one day available to me in Kiev was spent entirely with Glushkov. Since I had no time to explore my original hypotheses about research activity in Kiev, I was forced to obtain my information second hand from my host and his colleagues at the computing center.

1. There is little contact between the Institute of Higher Nervous Activity (Professor Amosov, Director) and the computing center research group. Glushkov knew of no activity at this institute on the construction of mechanical brain models, brain model simulation, nerve-net synthesis, or other theoretical or experimental work on brain functions (using either special purpose machines or computer programs). The extent of Glushkov's knowledge was that this institute has been doing some work in the area of medical diagnosis by computer.[13] [I find it difficult to believe that this is the actual state of affairs at Amosov's Institute. The institute was set up by special fiat at a cybernetics conference in Kiev in 1958 to foster cybernetic research in Kiev, and the title of the institute is indicative of what the Academy of Science had in mind in forming the group. However, no one in Moscow knew much about the group, which may indicate that they are indeed moving slowly.]

2. The computing center itself has no project in medical diagnosis by computer and is planning no such effort.

3. Glushkov knew of no work on nerve net synthesis, learning machines or thinking machines in Kiev.

4. Of the much-touted work on the so-called economic cybernetics (e.g. large-scale economic planning by machine), there is no work under way presently at the computer center. However, Glushkov expressed the hope that a project in this area would soon develop.

Machine economic planning is a research area of tremendous economic importance to the Soviet Union. Significant Russian progress in this area will increase Soviet economic potential. A criticism levied against the Soviet centralized (or relatively centralized) system for economic allocation of resources is that it is impossible to plan or coordinate centrally for an economy as large scale as the Soviet Union. The advent of sophisticated ways of using computers could change this. Large-scale, centralized, efficient economic planning and control by digital computers may be feasible in the relatively near future. Soviet progress in this area is something of great interest.

5. On the applications of computers to operations research problems, the center hopes to begin work soon in the area of linear programming. Specifically with regard to automatic construction of schedules, railway timetables, and similar problems, Glushkov knew of no such research project in Kiev.

I was not able to visit either the Institute for Electrical Engineering or the Institute for Automatics of Gosplan. However, from conversations with various American delegates, I understand that the directors of these institutes, Mr. Milach of the Institute for Electrical Engineering, and Mr. Melnik of the Institute for Automatics of Gosplan, would take trouble to meet reasonable requests for visits.

Brief Notes from Leningrad

In preparation for my visit to Leningrad, I wrote to Professor Vallender of the Computing Center of Leningrad University and Professor Kantorovich of the university. A month before I came to the city, Professor W. Reitman laid a foundation for other interesting contacts; one of these was the well-known and highly regarded physiologist, Madame Chistovich. In Moscow, scientist friends had suggested other people and places: Dr. Andreyev, of mechanical translation fame, and LOMI, the Leningrad division of the Steklov Mathematical Institute of the Academy of Sciences of the U.S.S.R. One of the projects of this institute is the develop-

[13] Herbert Pick (University of Wisconsin), in a private conversation, suggested that Amosov's Institute was studying thinking processes of individuals with brain damage.

ment of PRORAB languages, with which Kantorovich's name has been associated. I had many potential contacts in Leningrad and anticipated a heavy schedule of activity.

Although the midnight sun shone in Leningrad, the climate for cross-cultural contact was frigid. I was not the only American scientist in Leningrad at the time to experience this phenomenon. Other scientists, delegates of the IFAC conference, at least one of whom gave lectures in Leningrad during his visit, had equally difficult dealings. It was a frustrating few days. People were either out of town, unavailable, ill, or busy. Intourist made contacts difficult: when I asked Intourist to contact a Mr. Karimov for me (a lawyer interested in cybernetics), I was asked why a cybernetics scientist would want to speak with a lawyer.

LOMI. I had the address of LOMI, the Leningrad Division of the Steklov Mathematical Institute of the Academy of Sciences of the USSR; I took a taxi and arrived unannounced. They were indeed surprised. They held a quick conference and sent me back to the hotel, ostensibly for an interpreter. This was, in fact, a delay, for when I returned with the interpreter, she was of little use. She could not translate technical terms; the people at the institute spoke fairly good English; and besides, they were not in the mood to communicate.

LOMI is located in an old dilapidated building which it shares with another institute (which I believe is the Institute of Electromechanics). From what I could gather, LOMI has a STRELA computer, but I did not see it. They asked me to define carefully what I was interested in discussing. I mentioned non-algebraic computer languages, PRORAB languages, and the development of PRORAB languages at LOMI. Thus began one of the most non-communicative briefings I have ever experienced. Interspersed between comments of some information content was cross-chatter in Russian about what they could and could not tell me.

It seems that there are currently five classes of PRORAB languages: (1) Matrix PRORAB; (2) Polynomial PRORAB; (3) Algebraic Compiler PRORAB; (4) Universal PRORAB (or, as they later called it, Program PRORAB); and (5) Algebraic Transformation PRORAB. The only one of these we discussed was Polynomial PRORAB; I asked about Universal PRORAB, but received no answers.

Polynomial PRORAB is a non-arithmetic, analytic computer language for operating on polynomial expressions. Some of the operations which they mentioned as included in the language are truly remarkable for the current state of the art of symbol-manipulating languages—for example: differentiate a polynomial; integrate a polynomial; and solve a polynomial equation. It is difficult to believe that they, in fact, have what they say. The STRELA memory has only 2,048 memory cells. The PRORAB system for polynomials, they claim, occupies only 350 cells and the rest are available for working memory. They were annoyed when I expressed incredulity. I asked about the size of the programs which realized the individual operators. The differentiation operator, they claimed, was programmed with only 14 instructions. They showed me a sample of PRORAB programming, but it was impossible to decipher the example for it was coded entirely with numbers (they have no alphabetic devices).

OTHER INDIVIDUALS. Mr. Gerschuni whom I did not meet personally, of the Physiological Institue (Academy of Sciences, USSR) in Leningrad was mentioned as having an interest in sensory processes and information theory.[14]

Professor Kantorovich of the Leningrad University probably will not be located in Leningrad in the near future. He will be moving to Novosibirsk where he will direct work in mathematical economics. Madame Chistovich, the physiologist, will also be moving; she has been called to Moscow to the Academy of Sciences.

Intelligent Conversations on Intelligent Machines in Riga, Capital of the Latvian Republic

The program of a cybernetics conference held a few years ago in Kiev lists a paper on "Self-Instructing Electronic Computers" by E. I. Arin. I learned, while in Moscow, that Arin was Director of the Academy of Sciences Computing Center in Riga, Latvia.

DR. E. I. ARIN. Immediately after checking in at the hotel in Riga I phoned Arin. Much to my amazement, I was able to reach him with no trouble and a meeting was arranged in short order. In our conversations we were joined by a young scientist, speaking good English, who was directing the new mechanical translation project in Riga.

Until recently, Arin was Director of the Computing Center of the Latvian Academy of Sciences, a center which had only a small M-3 computer. Now, however, the computing center at the academy has been de-emphasized, and a major effort will be made to build a strong computing center at the Latvian State University at Riga. Arin was appointed Director of this center and for the past year has been working at the administrative task of organizing the center and obtaining a strong staff. Thus, his own research has come temporarily to a halt.

Arin mentioned that the focus of computing-machine activity was shifted from the academy to the university, for it was felt that education in this area was a high-priority goal. There is a prime need to train students, and it was felt that the computing center (in a city which could have only one) should be at the university. Arin estimated that by the end of the year the university would get its BESM-II computer. Following the Soviet style, some of the pieces (the adder and the frame) had arrived from Moscow, and Arin's engineers were assembling the machine. Arin wants to start the center with a nucleus of about 50 people; he is making trips to other cities in the U.S.S.R. to try to induce wellknown people to work with him in Riga. Incidentally, Riga, with its beach and generally favorable climate, is often mentioned by Russians as a beauty spot and a highly desirable place to visit.

Arin's plans for the computing center include (1) a strong group in differential equations and numerical methods for computers, and (2) a more theoretical section working on intelligence in machines and other advanced topics. It is interesting that he plans to build this second section mainly from his university students. His reason, he indicated, was that he had no other re-

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[14] Dr. W. Ross Adey, of UCLA, in recent private conversations about his visit to Leningrad, confirmed this report.

sources to tap in the field of intelligent machines in the other cities of the Soviet Union. He would have to train students.

The typical situation will prevail concerning the utilization of the computing center. The BESM-II will be the only big computer in Latvia. The center will handle the problems of the university and the problems of industry, which will have priority over basic research on computers. There will, of course, be an initial period of low utilization during which Arin and his students hope to get some research done. After that, most of the computing time will be occupied by higher priority problems, and Arin is pessimistic about the chances of doing research on this machine. Arin mentioned that the high-priority computing projects of the center were problems in quantum physics and crystallography.

ARIN'S WORK ON INTELLIGENT MACHINES. We discussed Arin's so-called self-instructing electronic computer. The work was accomplished in 1955 and 1956 at the Academy of Sciences' Computing Center in Moscow; Dr. Yershov was one of his good friends there and had helped him carry out this project.

Arin began the explanation of his problem-solving machine by reviewing an experiment of Pavolv.[15] In the experiment a monkey is taught the solution to a complex problem by first being taught the solutions to a series of simpler subproblems. Each new subproblem is built up from the previous problem by adding a new element to the task. In the experiment the monkey is taught to pick up and eat an orange. The orange is then encircled by a ring of fire. The monkey is provided with a cup of water. He learns to use the water to put out the fire, and then pick up the orange and eat it. The water is then made inaccessible. The monkey is given a jug; he learns to retrieve water to put out the fire, etc. Arin was motivated by the experiment to program this kind of learning mechanism for a computer to enable the machine to learn to solve complex problems.

The program learns to solve simple algebraic equations of three types.

Type I. $ax + bx + c = dx + ex + f$. The form of the answer is $x = f'$.

Type II. Two simultaneous equations in two variables, $ax + by = c$, $dx + ey = f$. The form of the answer is $x = c'$, $y = f'$.

Type III. Two simultaneous equations in three variables, $ax + by + cz = 0$, $dx + ey + fz = 0$. The form of the answer is $y = f_1(x)$, $z = f_2(x)$.

Only six parameters were used in all of the problems. Six memory cells held the values of the parameters a, b, c, d, e, f, which were initially set to zero, and a result form (or result vector) for each type of problem was stored. For example, for Type I problems the result vector was $(1, 0, 0, 0, 0, f')$. For Type II problems, the result vector was $(1, 0, c', 0, 1, f')$.

The rules of algebra were incorporated in the program as allowable transformations of the coefficients. For example, rule 1, a combining operation, transformed coefficient vector (a, b, c, d, e, f) into vector $(a+b, 0, c, d, e, f)$. Rule 2, multiplication by a constant k, transformed the coefficient vector into (ka, kb, kc, kd, ke, kf). Rule 3, multiplication of one equation by a constant k, transformed the coefficient vector into (ka, kb, kc, d, e, f). Naturally, not all rules are applicable to all problem types, but the machine keeps a list which associates problem types, result forms, and the list of rules applicable to problem types.

A restricted domain of integers is used: the set $z = [-50, -49, \cdots, +50]$ but not including $-1, 0, +1$.

The experimenter poses a Type I, II, or III problem to the program. The values in the six coefficient working cells are set to zero. A coefficient, a, b, c, d, e, or f is chosen randomly. The value for this coefficient is then chosen randomly from z. Thus, for example in a Type I problem, this step might give a vector $(0, 7, 0, 0, 0, 0)$, corresponding to the equation $0x + 7x + 0 = 0x + 0x + 0$; that is, $7x = 0$. Rules are now selected in an attempt to reduce this form to the form of the result for the problem type. The selection is performed randomly, but the rules have attached to them probability weightings of selection which vary with the experience of the program and which reflect the usefulness of particular rules in aiding problem solution. Hence, useful rules eventually achieve a high probability of selection. For any one event, a rule is judged useful if its application meets one of two criteria—a coefficient is reduced either to 0 or to 1. When the result form is achieved, the program which achieved the success—that is, the sequence of rules applied—is stored.

The entire problem is now repeated five times using this program with other randomly chosen coefficients. This is done as a test of the generality of the results. If success is achieved on all of the repeated trials using the program, then the program is considered a success, and the machine continues its learning.

The machine then adds another coefficient, chosen randomly from the set z, to the coefficient vector. For example, the vector might become $(0, 23, 0, 0, 0, 16)$. An attempt is made to find a set of additional program steps which will transform the new problem (slightly more complicated than the old one) into the form which the last program of rules was able to solve. The result is another program, this time slightly more complex. The process iterates until a program of rules is achieved which will solve problems in this problem type which have all six coefficients.

The machine language program which realizes this consists of 12,000 STRELA commands. The STRELA operates at 2,000 operations per second, and requires about 40 minutes to solve one problem with this procedure—that is, to work out the program of rules for solution of a particular problem type.

Any one of the problems which the machine works on as part of the "chain of problems" leading to the ultimate program for solving the problem with six coefficients is of this form: transform some equation form (specified by an "existence vector" for various coefficients, e.g. 1, 1, 0, 1, 1, 1) into the result form. When the machine discovers a program, it stores this program with a "key" that signals that this program transforms some "coefficient existence vector", v, into the result vector. At each successive stage of complication of the problem, (i.e. the building up of bigger programs) the machine searches for a rule which will transform the equation form with which it is working into a form for which a program already exists. For problem type I, this can always be done with the addition of one new program step at each complication of the problem. For problem types II and III, more than

[15] A description of Pavlov's experiment may be found in I. A. Poletaev, *Signal: O Nekotorykb Poniatiakh Kibernetiki*, Moscow, Sovetskoe Radio, 1958.

one additional program step is needed in general, but Arin has proved that no more than three are ever needed.

Suppose that more than one program step is needed. How is such a linked set of program steps arrived at? A single program step is attempted (say one involving the multiplicative constant k). If in two hundred trials with various k's this step does not produce a transformed form for which a program already exists, then it is assumed that this rule is no good and another rule is selected. When all the "one step" tries are exhausted, random combinations of "two steps" are tried, and so on. When I observed that this was a very inefficient procedure, Arin agreed, but said that in practice it wasn't so bad because of the action of the probability-weighting procedure for selecting rules.

What I understood least well in Arin's presentation was the procedure used for choosing k in the application of the multiplicative rules, say rules 2 and 3. Arin observed that choosing k randomly from combinations of elements of z was much too "unlikely" a procedure. Instead, k is computed in one of three forms: (a) $k = k'/k''$, (b) $k = k' \cdot k''$, (c) $k = k' + k''$, where k' is either a member of the set $u[-1, +1]$ or $v[z]$, and k'' is either a member of the set $u[a, b, c, d, e, f]$ or $v[z]$. For any particular trial k is chosen in the following manner: First, a form for k is randomly chosen (form (a), (b), or (c) above). Second, the set u or the set v (in the definition of k' and k'') is selected randomly. Third, particular elements in u or v (whichever is selected) are chosen randomly, giving a particular k' and a particular k''. Fourth k is computed. Initially, all the various alternatives in the random choices (which comprise the decision just described) are given equal probability. As the system accumulates experience, those alternatives which prove to be useful have their probabilities of selection incremented at the expense of the unsuccessful alternatives. Hence, finding the right kind of k becomes easier, in general, with the experience of the program.

Arin added one brief note. The process which selects k uses choice by "analogy." An example of the analogy heuristic is the following: if $1/b$ was a useful k in reducing one of the coefficients (b) to 1, then try other combinations of this form, say $1/a$, or $1/c$, to reduce other coefficients. We also discussed schemes for providing the program with examples and allowing it to discover the rules of algebra for itself, but this has not yet been done. Our conversation then moved on to a more general discussion of problem-solving machines.

Arin thinks of his algebra learning program as "a toy," an experiment devoid of useful purpose. He is unhappy with it because it is "too blind, too stupid." He clarified this to mean that it operates with too much randomness. It was designed in this way initially because he did not want to give the machine too much information about the task (remember, he took his cue from Pavlov's problem-solving monkey). Arin was particularly dissatisfied because his algebra machine "worked forward;" he felt that "working backwards" was necessary for effective problem solving. This statement led into our discussion of problem-solving heuristics.

Arin displayed a deep understanding of the research problem at the core of studies of intelligent machines. He diagramed a problem-solving task for me as a labyrinth of possible avenues toward a solution. He said that measures of progress toward the goal were essential for the solution of a problem. In problems of numerical approximation, the notion of progress was obvious. In intelligent problem solving, however, progress was much less clear. He mentioned the use of cues to constrain exploration of the labyrinth. Cues could come from the problem information itself, or from outside the problem, though he was not sure how one brings external cues to bear. To illustrate he offered this example: Suppose one knew that the goal-exit of the labyrinth was near an exterior pool of water. From inside the labyrinth one could throw out stones and listen for a splash. The sound of the splash could then direct the search toward the exit.

As Arin spoke on this topic, I saw that many of the basic pieces of the heuristic theory of problem solving as developed by Newell, Shaw, and Simon were present in his thinking. Interestingly enough, Arin seemed not to have thought of the role that experimental psychology might play in his research on intelligent machines, even though his work on the algebra machine was triggered off by an experiment of Pavlov's.

At one point in our discussion, I mentioned the Newell-Shaw-Simon chess-playing program. Unlike others I met, who dismissed the program as useless or impractical, Arin showed a keen interest. He was interested in writing a chess-playing program. He wanted to know what expert aid Newell, Shaw, and Simon had enlisted in designing their chess-playing program. His expert aid would be Michael Tal, the former world's chess champion who lives in Riga.[16] The goal of Arin's work will be to design a chess program to beat Michael Tal. Arin did not feel this was an impractical goal.

Arin's Speculation on Future Work. Dr. Arin and I discussed some of the more speculative ideas he has been considering. He proposes to model the human organism as an abstract machine and to search for the not-so-obvious properties of such a machine. Stated quite generally, he sees the human organism as a closed system, with input, output, and processes for self-organization, self-regulation, and self-maintenance. He proposes to model each separate subsystem of the body's machinery according to its particular function, focusing his analysis on the control of this machinery by a central computing device—his model of the central nervous system. Certain assumptions will be made about the nature of this central computing device and the machinery it controls—assumptions, for example, about its signal-transmission rate, its rate of failure, its rate of self-repair, and other properties of its self-regulation and self-maintenance machinery.

Arin posed the following question: Given a theory of the human machine constructed from a set of reasonable hypotheses about the body's machinery, can one deduce as a property of this machine that it is mortal? Or can it be proved that the machine might possibly live on indefinitely under certain conditions? Regardless of the chances of answering this question, or others like

[16] A recent and fascinating article, "Men and Machines at the Chessboard," *Soviet Review*, Vol. 2, No. 3, March, 1961, written by Botvinnik, the world's chess champion, cites Tal as saying that it is impossible to build an intelligent chess machine. Botvinnik himself, I understand, is helping to program a chess machine.

it, from this approach Arin believes that the research will have great theoretical, and perhaps practical, interest. Of course, he wants to study not only the mortality properties of the system, but also other theoretical properties of self-regulating, self-maintaining closed systems.

COMMENTS ON COMPUTERS. Arin and I briefly discussed the present state of Soviet computers. He said that they were having difficulty perfecting the process for making reliable transistors, but that the problem was gradually being solved and they would soon have fully transistorized machines. He admitted that computer time was scarce and, as I have already mentioned, was somewhat worried about the future of his own research.

EVALUATION AND CONCLUSION. I shall try to summarize briefly my impressions of Dr. Arin. His understanding of the problems of building intelligent machines is genuine and deep. He has discovered the appropriate constructs and terminology for discussing problem-solving by machines. His algebra machine cannot be classed now as an achievement of great lasting significance. But, on the other hand, it is neither trivial nor unimportant. Reflect on the fact that it was done in 1955 and 1956, roughly the time of the first successful heuristic problem-solving program written in this country.

There is the possibility that if Arin had had substantial computing power available to him during the past few years (instead of the use of only his very small M-3), he and his students might have independently discovered the Newell-Shaw-Simon formulation of heuristic problem-solving programs for computers. But that is a big "if." The essential point is that Arin did not have this computing power available to him. His research has no computing priority. He does his research in his spare time, as it were. At the present time Arin has an administrative role which will further constrain his research activities.

Some Observations on the State of Computer Technology in the Soviet Union

I concur with the opinion of most U. S. computer scientists who have visited Russia that at present the United States has a definite lead over the Soviet Union in the design and production of computing machines, but that there is no gap in fundamental ideas, with the possible exception of the production of reliable transistors. With the importance of computers to modern science and technology, there is no doubt that fairly soon the Soviet Union will be producing as many computers as we do. To what extent they will utilize these computers effectively, and in what new ways, I have no immediate answer, but my trip did provide me with a few indications.

1. There appears to be a substantial body of high-caliber scientists and mathematicians particularly in Moscow and Kiev, and perhaps in a few other places, who are informed, interested, and active in such research areas as cybernetic theory, brain models, learning machines, computer control of information, languages, and computer utilization in economic planning. If the reader wants to convince himself of this observation, I suggest that he scan the table of contents of the impressive five-volume series of *Problems in Cybernetics*,[17] edited by Lyapunov. It is not insignificant either that the active motive force behind this work was, and still is, A. A. Lyapunov, one of the foremost mathematicians in the world today.

2. It appears that research in the computer sciences is directly centrally from Moscow. This unstartling observation is meant to imply that there seems to be little place for independent inquiry motivated by curiosity in this new and relatively unstructured research area. But where will the new ideas for the next generation of research come from? From the West? In that case, there will always be a lag between their research and ours.

Once the decision is made in Moscow to push a particular kind of research, resources can be concentrated. The mechanical translation effort is a case in point. Has the decision been taken to make a comparable effort in the area of artificial intelligence? This is not yet clear. There is some evidence that initial steps have been taken, but as yet the evidence from results is minimal.

3. They are training students on a broad scale in Moscow, in Kiev, Leningrad, Riga—yes, even in Yerevan. This is an investment of great significance. Dr. Yershov himself was a student of Lyapunov in Moscow just a few years ago. Their pool of competent scientists oriented toward cybernetics and advanced application of computers is growing. The full exercise of this potential will await a time when computing machine resources are less scarce and can be diverted with some priority to the research.

[17] Lyapunov, A. A., ed., *Problems in Cybernetics*, Vols. I–V, Moscow, State Publishing House for Physical and Mathematical Literature, 1959–1961.

Epilogue

This report was written in late 1960. In a research area as dynamic as the computer sciences, it is inevitable that such a report is soon a bit out of date. I should like to update the report by mentioning a few Soviet developments which have recently come to my attention.

1. Volume 5 of *Problems in Cybernetics* has been published. It includes a new section, "Problems in Mathematical Economics." In the Preface, the editor, Lyapunov, writes that mathematical economics "... is at present becoming very important," and he cites a number of references to publications in linear programming (including translations of important American work in the field).

2. An article in the English-language *Moscow News* of August 12, 1961 entitled "The Mechanical Mind and Creative Endeavor" cites some Soviet research in artificial intelligence. Among the projects mentioned is that of Professor Amosov (Institute of Higher Nervous Activity, Kiev) on medical diagnosis by computer. A music composition program by R. Zaripov, of the University in Rostov-on-Don, is also described.

A complete translation of the research report on music-composition with the URAL computer will be found in *Automation Express*, November, 1960. The program itself is not very interesting. It is significant, however, that in a provincial, "small computer" city, research of this type is being given some priority for scarce computer time.

The same thought recurs with regard to reports of recent Russian attempts to program a chess-playing machine. During my trip, I discussed chess-playing programs with a number of Soviet scientists and no one, with the exception of Dr. Arin, thought that these programs amounted to anything more than a frivolous waste of valuable resources.

Yet a group, reported to contain Botvinnik, chess champion and engineer, is now attempting to write such a program and computer time (on a BESM-II, it is reported) is being allocated for this effort.

3. Though these few swallows do not yet make a summer, the implication is that computer time is becoming less scarce and that research on artificial intelligence and other advanced applications of computers is beginning to achieve a priority which it did not seem to have just one year ago.

Acknowledgment

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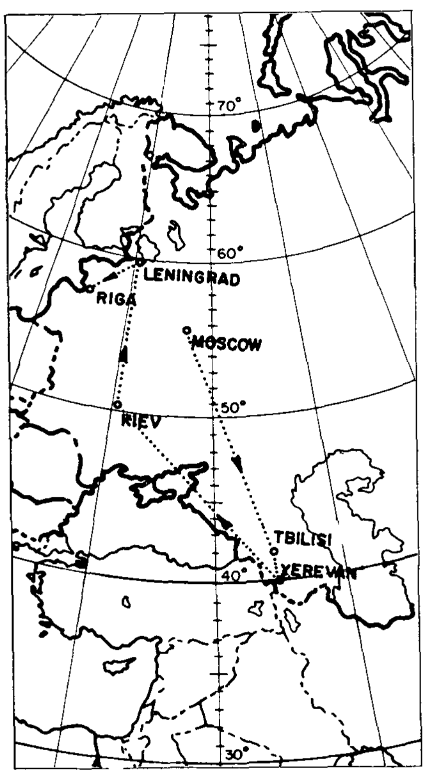
APPENDIX A

Itinerary



APPENDIX B

Organization of the IFAC Conference

1. THEORY
1.1 Theory of Continuous Linear Systems
1.2 Theory of Continuous Non-Linear Systems
1.3 Theory of Discrete Systems
1.4 Stochastic Problems
1.5 Theory of Optimum Systems
1.6 Theory of Self-Adaptive Systems
1.7 Theory of Structures and Methods of Signal Design
1.8 Special Problems of Mathematics
1.9 Simulation and Experimental Methods
2. COMPONENTS
2.1 Electric and Magnetic Elements of Control Systems
2.2 Electric Computing and Analog Devices, Programming Elements and Controlling Machines
2.3 Transducers, Elements and Systems of Automatic and Remote Process Control
2.4 Pneumatic Automatic and Computing Devices
2.5 Devices and Systems of Automatic Control
3. INDUSTRIAL APPLICATIONS
3.1 Automation in Machinebuilding
3.2 Automation of Power Systems
3.3 Automation in Chemical and Oil-Refining Industries
3.4 Automatic Electric Drives and Electric Machines
3.5 Automation of Metallurgical Processes
3.6 Non-Classified Problems
4. GENERAL PROBLEMS

APPENDIX C

Technical Excursions: Institutions Visited by Delegates of the 1st International IFAC Congress

Moscow, June 27–July 7

INSTITUTE OF AUTOMATION AND TELEMECHANICS, U.S.S.R. ACADEMY OF SCIENCES: automatic control systems (adaptive, etc); telemechanical control systems (for oil fields, coal mines and power systems); electric, pneumatic and hydraulic devices for automatic control systems; analog computers.

COMPUTATION CENTER, U.S.S.R. ACADEMY OF SCIENCES: URAL and BESM-II electronic computers for mathematical problems.

INSTITUTE OF MINING, U.S.S.R. ACADEMY OF SCIENCES: automatic and remote control systems for the coal-mining and ore-mining industries.

MOSCOW STATE UNIVERSITY: general principles of instruction and teaching methods; work in progress at the chairs of theoretical mechanics and computer techniques.

MOSCOW POWER INSTITUTE: general principles of instruction and teaching methods; work in progress at the general science and specialized chairs.

FIRST STATE BEARING FACTORY: fully automatic production lines for the manufacture of bearings.

"KRASNY PROLETARIY" MACHINE-TOOL FACTORY: integrated automatic gear manufacture line; lathe assembly line.

MOSCOW SMALL-POWER CAR FACTORY: automatic lines for machining engine parts.

SECOND STATE WATCH AND CLOCK FACTORY: watch assembly line.

POWER STATION 20 OF THE MOSCOW POWER SYSTEM: automatic control of boilers.

LOAD DISPATCH CENTER OF THE MOSCOW POWER SYSTEM: automatic and telemetering control of power systems.

CONTROL CENTER OF THE MOSKVA CANAL (YAKHROMA, MOSCOW REGION): telemechanical control of pumping stations.

Leningrad, July 4–July 7

INSTITUTE OF ELECTROMECHANICS, U.S.S.R. ACADEMY OF SCIENCES: electro-dynamic analog for a power system, automatic control of telescopes, frequency converters.

LENINGRAD INSTITUTE OF ELECTRICAL ENGINEERS: general principles of instruction and teaching methods; research program of general science and specialized chairs.

STATE OBSERVATORY, U.S.S.R. ACADEMY OF SCIENCES (PULKOVO): tour of the Observatory; astronomic instruments and devices used (a device for timing stars crossing the Pulkovo meridian, photo-electric coordinate reader); Laboratory of Radio Astronomy (radio-telescope).

"VIBRATOR" PLANT: manufacture of electrical measuring instruments: high-grade precision laboratory instruments, multi-channel recording oscillograph, photo-call instruments, manufacturing technology of miniature parts.

SVERDLOV MACHINE-TOOL FACTORY: manufacture of program-controlled jig borers and semiautomatic machine-tools (copying machine-tools, etc.).

DISTILLERY: automated shop (washing, bottling, corking).

Kiev, July 4–July 7

COMPUTATION CENTER, UKRAINIAN ACADEMY OF SCIENCES: The KIEV, URAL, and SESM electronic computers for mathematical problems.

THE PATON ELECTRIC WELDING INSTITUTE, UKRAINIAN ACADEMY OF SCIENCES: new welding techniques and equipment.

INSTITUTE OF AUTOMATION, UKRAINIAN ACADEMY OF SCIENCES: automatic control systems for iron-and-steel and chemical works, power systems, coal and ore mining, gas fields and engineering factories.

"TOCHELECTROPRIBOR" PLANT: process control in plastic parts shops, and assembly line for high-grade electric measuring instruments.