From Newspeak to Cyberspeak

A History of Soviet Cybernetics

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5

The "Cybernetization" of Soviet Science

[Cybernetics] aspires to study all control processes in living nature, in production, and in human society, that is, to embrace practically all human activity.
—Engineer Admiral Aksel' Berg, chairman of the Council on Cybernetics[1]

In the late 1950s, the popular image of an "objective," truth-telling computer became a vehicle for the emerging cybernetic discourse. Soviet mathematicians and computer specialists began to fashion a new discipline that would provide theoretical and practical guidance to computer modeling and supply techniques and technologies for transforming scientific knowledge into computer models and testing its validity. Soviet cyberneticians aspired to unify several diverse cybernetic theories elaborated in the West—control theory, information theory, computation theory, and others—in a single overarching conceptual framework that would serve as the foundation for a general scientific methodology applicable to a wide range of scientific and engineering disciplines.

The farther Soviet society departed from Stalinism, the more radical the cybernetic project became. Step by step, Soviet cyberneticians overturned earlier ideological criticisms of mathematical methods in various disciplines and put forward the goal of the "cybernetization" of the entire science enterprise—a much more ambitious agenda than was originally envisioned by Norbert Wiener in *Cybernetics*. A new concept of scientific objectivity associated with mathematics and computing lay at the core of this project. The Soviet cybernetics movement had a special mission: to bring objectivity to the entire family of the life sciences and the social sciences. Soviet cyberneticians believed that could accomplish this task by translating these sciences into cyberspeak. The precise language of cybernetics was to replace the vague and manipulative language of ideological discourse in fields that mathematics had not yet reached.

Having rejected the dominant role of philosophy in academic discourse, Soviet scientists put forward cybernetics as a substitute. They rejected a dogmatic Soviet version of dialectical materialism, but they accepted the premise that a universal philosophy of science, a general scientific methodology, or a meta-science was needed. Soviet cybernetics was constructed specifically to fulfill this function. In the United States, Wiener's original eclectic synthesis of diverse scientific and engineering concepts did not hold together; various threads of the cybernetic quilt—computing, control engineering, information theory, operations research, game theory—soon parted ways. Soviet cyberneticians, on the contrary, regarded cybernetics as the potential basis for a grand unification of human knowledge.

The cybernetics movement enveloped a broad range of disciplines, including mathematics, biology, physiology, linguistics, psychology, chemistry, economics, and legal studies. Cybernetics enthusiasts in different fields, however, often had very different ideas about the nature of a cybernetic approach. The disciplines brought under the cybernetic umbrella were unified at best by a Wittgensteinian "family resemblance." Defining the subject, the methods, and the theoretical principles of their discipline became an ongoing project of Soviet cyberneticians. In cybernetics, intellectual issues were closely intertwined with political debates and institutional disputes, and those disputes often focused on the meaning and the limitations of cyberspeak.

Cybernetics as a "Trading Zone"

Soviet cybernetics emerged in the Khrushchev era as a cross-disciplinary project that challenged some of the main dogmas of Stalinist academic discourse, particularly the rigid boundaries between scientific disciplines. During the Stalin era, such epistemological barriers served a political purpose: to invalidate the use of mathematical methods in the social sciences and the life sciences and to claim a special status for "natural historical laws" and "biological laws." Supporters of the infamous hack scientist Trofim Lysenko argued that biological laws could not be proved or disproved by mathematical or statistical means but only "on the basis of biology" (meaning the Lysenkoist doctrine). Lysenkoites portrayed mathematical processing of the results of genetic experiments as an impersonal, formal procedure that pulled the researcher away from the field, from nature, and from the

truth. "We, biologists, do not take the slightest interest in mathematical calculations which confirm the useless statistical formulas of the Mendelists," proclaimed Lysenko. "We, biologists, . . . maintain that biological regularities do not resemble mathematical laws."[2] In the Stalinist system of science, each discipline was usually dominated by one officially endorsed school—e.g., the supporters of Lysenko in biology and the followers of Pavlov in physiology. The epistemological barriers between scientific disciplines helped the dominant school to protect its intellectual and institutional authority.

While liberal writers were searching for truth untainted by ideological canons, liberal scientists were looking for universal, objective scientific methods that would overcome the legacy of ideological dogmatism in various disciplines. The mathematician Andrei Markov Jr. summarized this contemporary sentiment as follows:

> One must not subdivide science into separate specialties with impenetrable fences, claiming that physicists should do [only] physics, mathematicians—mathematics, and biologists—biology. I think this trend is totally wrong and harmful. Science in essence is one, and all our classifications of the sciences are conventional. . . . Nature is one, and the sciences in essence comprise a single entity.[3]

Liberal scientists chose cybernetics as their primary weapon to break interdisciplinary barriers and legitimize the use of mathematical methods in the social sciences and the life sciences. They viewed cybernetics as an "exact science"[4] that, if applied to a given field of inquiry, would be capable of transforming that field into a rigorous research discipline. As one science journalist put it: "Cybernetics is probably the only possible instrument for reassembling the falling apart temple of science."[5]

Soviet authors called for a comprehensive "cybernetization" of modern science—that is, for representing the subject of every discipline in a unified, "formalized" way and moving toward a synthesis of the sciences.[6] In this sense, Soviet cybernetics was not a settled discipline but rather an ambitious project of systematic translation of scientific discourse into cyberspeak, which would make it possible for mathematical methods and computer models to penetrate the sciences without restraint.

Soviet cybernetics emerged as a "trading zone" where specialists from mathematics, computer engineering, biology, and physiology would meet and trade their theories, methods, concepts, and hypotheses. Gradually the nomenclature of the traded goods expanded to include theories and concepts from sociology, economics, linguistics, psychology, and many other fields. Cyberspeak served as a mediating language, a creole of sorts for this interdisciplinary trade. Cyberneticians themselves called it a "technical-mathematical-biological-psychological scientific language" to emphasize its interdisciplinary character.[7] By declaring cyberspeak a universal language of science, Soviet cyberneticians aimed at a radical transformation of the entire science enterprise along the path of mathematical formalization and computer modeling.

To emphasize the new mediating role of cybernetics, Soviet authors often presented their own versions of the "tree of knowledge." For example, in a chart drawn by Leonid Kraizmer, a leading Leningrad cybernetician, cybernetics lies at the center and ties all the natural sciences, the social sciences, and the humanities together. "Cybernetics," wrote Kraizmer, "embraces all sciences—not entirely, but only in the part related to control processes."[8] In full accord with the official view of dialectical materialism as a "science of all sciences," philosophy reigns over this kingdom of sciences. However, one cannot help but notice that cybernetics is the only field that is not subordinate to philosophy. Aleksei Liapunov, who led the cybernetics movement in Moscow and later in Akademgorodok in Siberia, envisioned a similar role for cybernetics—in the center of the tree of knowledge. Known for his aversion to the official philosophical discourse, Liapunov skipped philosophy altogether in his chart. He placed logic and mathematics at the top of his hierarchy of sciences. Cybernetics, along with physics and statistics, again takes the central position; its function is to provide methods for the natural sciences, engineering, and the humanities.

In Liapunov's view, cybernetics embraced all uses of computers for modeling and control. A crucial step in the "cybernetization" of various disciplines was the "algorithmization" of disciplinary knowledge, or its translation into cyberspeak:

> If until recently the algorithmic approach to the description of processes has been used in mathematics, mathematical logic, and some fields of technology, now the algorithmic approach to the description of phenomena must be sharply broadened and enter many new sciences. For example, the algorithmization of technological processes is required for production control; the algorithmization of linguistic processes is required for the implementation of machine translation. To transfer a wide range of human functions to a machine, the algorithmic modeling of the functions of thought and behavior is required, and here cybernetics borders upon biology and psychology.[9]

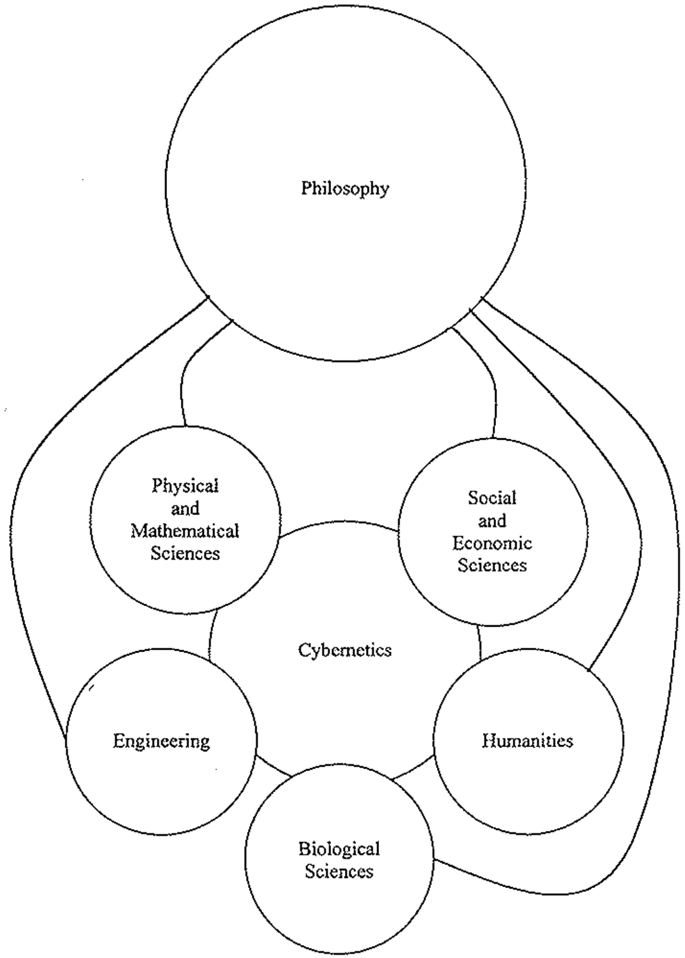

Figure 5.1
The interdisciplinary role of cybernetics. Adapted from Kraizmer, *Kibernetika*.

With Sergei Iablonskii, a colleague at the Applied Mathematics Division, Liapunov summarized the "cybernetization of science" project in a huge table, which included twelve methods of cybernetic analysis, such as determining information flows, deciphering the information code, and determining the functions and elements of a control system. Each method could be applied to each of the eight scientific and engineering disciplines listed

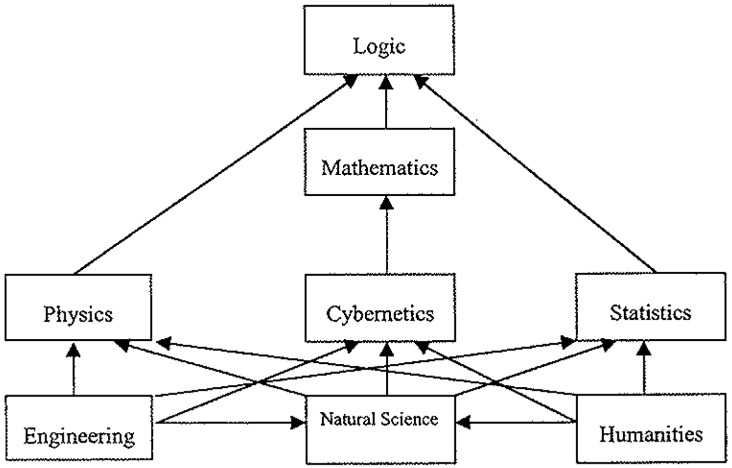

Figure 5.2
The system of relations among the sciences. Adapted from Liapunov, *Problemy teoreticheskoi i prikladnoi kibernetiki.*

in the table.[10] Liapunov often brought a human-size copy of this table with him to his public lectures on cybernetics. In 1956–57 Liapunov and his associates delivered more than a hundred such lectures before various scientific, engineering, and public audiences.[11] (For a condensed version of this table, showing eight methods of analysis, see figure 5.3.)

Evolutionary biologists, geneticists, linguists, physiologists, economists, and computer scientists all found places for themselves in this grand design. The cybernetics movement began to spread over a wide range of disciplines. "Biological cyberneticians" challenged the Lysenkoites in biology; "physiological cyberneticians" opposed the Pavlovian school in physiology; "cybernetic linguists" confronted the traditionalists in linguistics. The opponents of dominant schools in various fields began speaking the language of cybernetics.

The Council on Cybernetics as an Institutional "Umbrella"

To implement his far-reaching program of the "cybernetization" of Soviet science, Liapunov took steps to institutionalize cybernetic research in the Soviet Union. He thought that a loosely organized scientific council subordinated directly to the presidium of the Soviet Academy of Sciences would

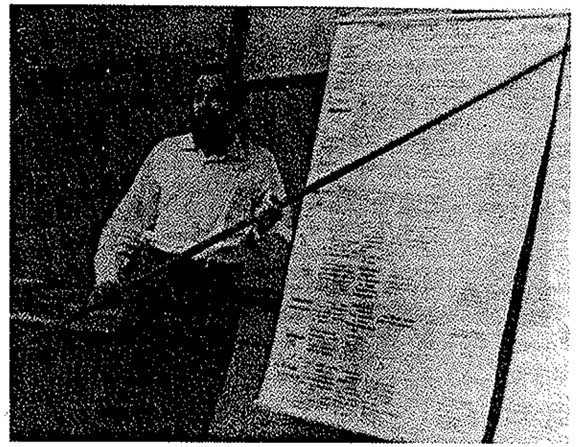

Figure 5.3
Aleksei Liapunov lecturing on cybernetics.

best fulfill the mediating and universalizing mission of cybernetics. At that time, Liapunov was not a member of the Academy and lacked necessary political influence and administrative skills to head such a council, so he asked Academician Aksel' Berg, who had just retired as Deputy Minister of Defense in charge of radioelectronics, to fill that post. Berg agreed, and his strong personality had a decisive effect on Soviet cybernetics.

Aksel' Ivanovich Berg (1893–1979) was born into a prominent noble family in Orenburg; his father was a retired general of the Tsarist army.[12] Berg served in the Imperial Navy during World War I. After the Russian Revolution, he became a submarine commander in the Red Navy. In 1925 he graduated from the Leningrad Navy Academy, specializing in radio engineering. Berg then served in various Navy research institutions, and in 1932 he became the head of the Naval Scientific Research Institute of Communication. In December of 1937, on the wave of the Great Terror, he was arrested on trumped-up charges and thrown into prison. In May of 1940 all charges were dismissed; Berg was released and again appointed to a responsible post. Legend has it that Stalin himself met with Berg and asked him, "Aksel' Ivanovich, what are you doing in jail, while this country needs your service?"[13] In 1943 Berg was appointed Deputy Chairman of the State Defense Committee Council on Radar and Deputy People's Commissar of Electrical Industry of the Soviet Union. He joined the Communist Party in

TASK	DESCRIPTION	MATHEMATICAL APPARATUS	COMPUTER SCIENCE	ECONOMICS	HARDWARE DESIGN	PRODUCTION CONTROL	LINGUISTICS	GENETICS	EVOLUTION-ARY THEORY	NEURO-PHYSIOLOGY
1. Determine information flows	Determine connections with environment and external memory	Observation	Memory allocation	Study the distribution of information that controls the economy (economic documentation)	Study the flows of information in a computer	Study the flows of information that controls production		Study the methods of transmitting hereditary information	Study the flows of information that controls evolution	Study the circulation of information in the nervous system and in the receptors
2. Determine the information code	Determine how information is coded	Statistical and logical analysis, coding theory	Creating a language for task formulation, input, and output	Study the methods of economic information coding	Study the methods of coding numbers and operators in a computer	Study the methods of information coding in production control	Study the methods of linguistic information coding in a computer	Study the methods of hereditary information coding	Study the methods of coding of information that controls evolution	Study the methods of information coding in the nervous system and in the receptors
3. Determine the functions of a control system	Setting specific time intervals, determine the functions of a control system	Cybernetic experiment, probabilistic processes	Determine the function of a computer program	Study the functioning of systems that control the economy	Determine if the computer functions according to design	Determine the function of production control	Study the possibility of machine translation algorithms	Study the ways in which genotype is expressed (phenogenetics)	Study the evolution of populations under specific conditions	Study reactions, reflexes, and behavior of animals
4. Study the functioning of a control system	Evaluate the achievement of goals, organization, and communication	Information theory, game and automata theory, operations research	Evaluate the entropy of various task classes and the redundancy of various coding methods; evaluate working time and computer time	Evaluate the amount of information, channel capacity, transmission time, and methods of decision-making and self-regulation	Evaluate the amount of information in the computer and its productivity, and collect operations statistics	Analyze operations, evaluate the amount of information, channel capacity, and information delays	Evaluate the entropy of text classes and information search tasks; evaluate work time and computer time	Evaluate the amount and study the transmission of genetic information, mutation and selection	Evaluate the amount of information that controls evolution; study population dynamics	Evaluate the amount of information and channel capacity of the nervous system; derive its structure from its functioning
5. Determine the elements of a control system	Determine the elements, study their properties, and classify them by types	Statistical analysis, logical analysis	Determine the classes of operators and develop standard subroutines	Determine the elements of economic processes and the elements of economic regions; use statistics to determine their functions	Design elements and storage devices	Determine the chain of production control and the functions of its links; develop standardized links	Determine the elementary acts of linguistic algorithms and develop methods of implementation	Determine the biochemical carriers of hereditary information ("the gene problem")	Determine the elementary acts at the basis of evolution ("evolutionary factors")	Determine the elementary constituents of the nervous system, the receptors, and their elementary reactions
6. Study the relations among the elements	Determine all the relations essential for the functioning of the system	Cybernetic experiment, graph theory, network theory	Determine the types of relations between different operators	Study the relations among the elements of economic processes and among the elements of economic regions	Study the interaction of elements	Determine the relations among links and classify them by types	Determine the relations among different operators in linguistic algorithms	Study the structure of genotype, the localization of genes, and the structure of DNA	Study the interactions of different evolutionary factors	Study the relations among individual organs of the nervous system
7. Determine the algorithms of a control system	Determine the (approximate) algorithms of a certain class of control systems	Cybernetic experiment, game theory, theory of algorithms	Develop algorithms of automatic programming and automatic program testing	Develop approximate algorithms for controlling the economy	Give a formal description of the structure and functioning of machines	Develop (possibly, approximate) algorithms for production control	Develop algorithms for machine translation and information systems	Develop an algorithmic description of the transmission of hereditary information	Study the circulation of information that controls evolution	Develop an algorithmic description of the functioning of the nervous system and the receptors
8. Analysis of a control system	Study the properties of algorithmic control	Information theory, game theory, linear programming	Derive an algorithm from a program; study the completeness of a programming method for a given class	Analyze the control of the economy	Study statistics of the operation of circuits	Study algorithms of production control; collect production statistics	Experiment with algorithms for machine translation and information systems	Perform a genetic analysis of individual organisms and populations	Study population dynamics and the struggle for existence	Study algorithms of information processing in the nervous system

Figure 5.4
Methods and fields of cybernetic analysis. Adapted from Liapunov and Iablonskii, "Teoreticheskie problemy kibernetiki."

1944, and he remained a dedicated communist for the rest of his life. In 1946 he was elected a full member of the Academy of Sciences. In 1953 he became Deputy Minister of Defense, but 4 years later, after a severe heart attack, had to retire for health reasons. In 1957–1960 Berg served as consultant to the Ministry of Defense, and in 1958–59 he headed the Scientific Technical Council of the State Planning Committee on complex mechanization and automation of production.

Berg brought to the cause of cybernetics the same energy and organizational skills that had served him well during the war. In January of 1959

Figure 5.5
Aksel' Berg (standing). Courtesy of Russian Academy of Sciences Archive, Moscow.

the presidium of the Academy of Sciences appointed a commission headed by Berg to examine the prospects of cybernetic research. He mobilized a large group of experts to write a fundamental report on the state of cybernetics. The preparation of the report took 3 months, instead of the allotted 2 weeks, but it produced remarkable results. On 10 April 1959 Berg delivered this report to the presidium of the Academy. The day before, he sent a note to Liapunov, who was the real driving force behind the cybernetics initiative: "Dear Aleksei Andreevich! Please review the text of my report for tomorrow's session of the presidium and make *any* corrections."[14]

In his report, Berg argued that cybernetic research in the Soviet Union was scattered in numerous institutions stretched over vast geographical areas and divided by bureaucratic barriers. He emphasized the need for a central organ that would coordinate this research in the entire Soviet Union. In his unpublished remarks during the session, Berg drew a gloomy picture of the current situation with computerized production control:

> There is not a single production control machine working now in the Soviet Union. . . . Electronic machines do not control a single production process anywhere [in the Soviet Union], but they will in the next few years. . . . After a number of institutions were united under a single Special Committee headed by Kalmykov, proper organization of work still has not been achieved. There is no proper contact between [the computer plant in] Penza, [the computer plant in Erevan headed by] Mergelian, and our Moscow institutions, even on specific questions.[15]

The presidium resolved to establish the Scientific Council on Cybernetics and proposed Berg as chairman. Berg frankly admitted that he was no big expert on cybernetics:

> I have no idea how I got into the chairman's seat. A. A. Liapunov came and told me that they asked me to be chairman. Nevertheless, I think that a prominent mathematician like Keldysh or someone else should be the head. Although I have worked a lot in this field, there is no reason for me to become the head. I am not quite fit for this; I do not know everything. I would simply say that I do not know enough, and I would not be able to do this job like a specialist would. I am not saying this out of modesty; this is really so.[16]

The president of the Academy, Aleksandr Nesmeianov, replied:

> Judging by the state of cybernetics, there are no people around who would know everything, for even the boundaries [of this field] are not clear. I think we should confirm the leadership of the Council as is, and later work will tell.[17]

Berg was appointed chairman, and Liapunov became his deputy.

Berg, with his strong connections and considerable influence in the government and among the military, became a powerful advocate of cybernetics. He secured funding for cybernetics conferences and workshops, obtained permission for the translation of foreign books on cybernetics (particularly Wiener's books), and widely publicized cybernetics in the press, on the radio, and on TV. Berg originally divided the Council on Cybernetics into eight disciplinary sections: mathematics, engineering, economics, mathematical machines (i.e., computers), biology, linguistics, reliability theory, and a "special section" (presumably, military research).[18] Each section coordinated cybernetic research in the corresponding field nationwide. The number of sections grew rapidly. First, philosophy and psychology sections were added, then a transportation section. By 1967 the number of sections had reached fifteen. The structure of the Council fully reflected the mediating role of cybernetics expressed in the charts of the "tree of knowledge" drawn by Soviet cyberneticians.

A large number of research trends marginalized in the strictly hierarchical Soviet academic community found a safe haven in Berg's council.

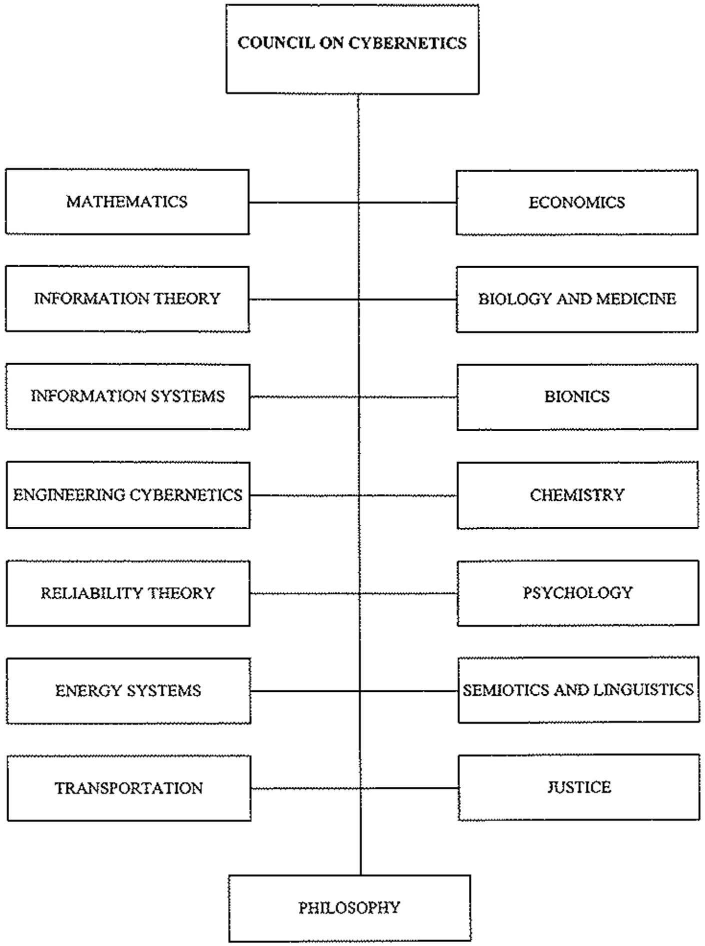

Figure 5.6
The structure of the Scientific Council on Cybernetics of the Soviet Academy of Sciences. Adapted from Berg, ed., *Kibernetiku—na sluzhbu kommunizmu*, volume 5.

Cybernetics served as an institutional "umbrella" for non-Pavlovian physiology ("physiological cybernetics"), structural linguistics ("cybernetic linguistics"), and new approaches in experiment planning ("chemical cybernetics") and legal studies ("legal cybernetics"). With the Council's support, unorthodox researchers were able to publish papers, convene conferences, and effectively legitimize their work as a part of a unified national

plan of cybernetic research. Liapunov worked tirelessly to teach scientists cyberspeak and to help them "cybernetize" their fields. One of his disciples has recalled:

Aleksei Andreevich [Liapunov] used to say that when he contacted scientists from other fields, he spent up to half of the time on the elaboration of a common language. Often the contact would end right there. Once that stage was passed successfully, however, wide possibilities for building up a mathematical theory [for a new field] would open up. [This happened,] of course, when the discipline in question was mature and rich with experimental material. This happened, for example, in mathematical genetics.[19]

Soviet genetics, suffering from the Lysenkoites' onslaught, was probably the discipline most eager to enter a strategic alliance with cybernetics.

Biological Cybernetics: Genes as "Units of Hereditary Information"

After Stalin's death, Soviet geneticists were able to regain some of the positions they had lost after the infamous July-August 1948 session of the Academy of Agricultural Sciences. Lysenko, however, quickly managed to win Khrushchev's personal support, and genetics went "underground" again. As the historian Mark Adams has demonstrated, genetics "hid under protective language: to cognoscenti, such terms as 'radio-biology,' 'radiation bio-physics,' and 'physico-chemical biology' functioned as a kind of protective mimicry, serving as euphemisms for both orthodox genetics and molecular biology."[20] Genetic research was conducted not in biological institutions (which were controlled by the Lysenkoites) but under the roofs of physical and chemical research institutes. One of the code names for genetics in this period was *cybernetic biology*.

Supporters of genetics among the leading Soviet cyberneticians began translating the problem of heredity—the central issue over which Soviet geneticists clashed with Lysenkoites—into the language of cybernetics. In October of 1958, at the All-Union Conference on Philosophical Problems of Natural Science, Aleksei Liapunov and Sergei Sobolev delivered a paper in which they portrayed genetics as an implementation of the cybernetic approach in biology:

On close examination, it turns out that what is transmitted from the parents to their offspring by inheritance is *hereditary information*. The task of genetics is to study the structure and methods of material coding of this information and the forms of its expression in a new organism in the process of individual development.[21]

When translated into cyberspeak, genetics became an information science. As Sobolev put it: "A living organism develops out of certain embryonic cells in which somewhere lies *information* received from the parents' organisms. This is not physics, this is not physiology; this is the science of the transmission of information."[22]

Liapunov and Sobolev also translated some of the postulates of Lysenko's doctrine into the language of cybernetics, only to show that it failed the cybernetic test:

> The thesis . . . that predominantly favorable traits are transmitted by inheritance requires, to be firmly established, the existence of a flow of hereditary information from the organisms of the offspring to the organisms of the parents. The existence of such a flow, however, seems quite problematic. . . . In the same way, the claim of the inheritance of acquired traits is equivalent to the assertion that there exists a flow of information coming into embryonic cells about the structure of the organism as a whole or its separate organs. . . . The fact is that the flow of hereditary information, traveling from an organism as a whole to its embryonic cells, lies unknown. . . . On the other hand, the data of classical genetics fully correspond to the ideas advanced in cybernetics.[23]

Liapunov became the head of the Biological Section of the Council on Cybernetics; as the editor of the series *Problemy kibernetiki*, published under the Council's auspices, he opened a regular rubric, "Control Processes in Living Organisms," in which he published works on genetics. In particular, Liapunov helped his close friend Nikolai Timoféeff-Ressovsky, a leading specialist in radiation biology, to resume active research and publications after returning from Stalinist labor camps. Timoféeff-Ressovsky's first lecture after his return to Moscow was given at an informal gathering in Liapunov's apartment.[24] The Lysenko clique shunned Timoféeff-Ressovsky, and cautious editors of biological journals controlled by the Lysenkoites turned down the first article he wrote after his return. Thanks to Liapunov's efforts, however, this article, written in collaboration with the geneticist Raisa Berg, appeared in the fifth volume of *Problemy kibernetiki* in 1962.[25] To justify this publication, Timoféeff-Ressovsky and Berg injected a few cybernetic terms in their article. They wrote, for example: "Genotype is a control system that determines the ontogenesis of living organisms and at the same time it is a code of hereditary information, which is transmitted from generation to generation."[26] In 1959–1967 Timoféeff-Ressovsky published seven articles in *Problemy kibernetiki*. In 1958 Raisa Berg organized an interdisciplinary seminar on "Cybernetics and Genetics" at Leningrad University. She later recalled: "Cybernetics, biochemistry, biophysics, mathematical methods in biology, systems theory—all of that was now [in Khrushchev's time] possible, and the languages of these sciences became the Aesopian language of genetics. A 'unit of hereditary information' sounded less anti-Lysenkoist than a 'gene.'"[27]

The strategic alliance between genetics and cybernetics did not escape the attention of the Lysenkoites. They counterattacked, accusing geneticists of the frivolous use of the language of cybernetics. In early 1962 the Lysenkoites submitted to the State Publishing House of Physical and Mathematical Literature a highly negative 20-page review of biological articles published in *Problemy kibernetiki*. According to this review, cyberneticians had interpreted the notion of information too broadly and had illegitimately extended this notion to biology, which had resulted in grave ideological mistakes:

> The volumes of *Problemy kibernetiki* became a "mouthpiece of anti-Michurinism." . . . As an example of "information," [cyberneticians] point out the influence of the environment on the organisms of animals and humans. If so, then the technical meaning of the term *information* in cybernetics is lost. . . . The attempts to view any communication as [the transmission of] information can only be interpreted as the intentional or unintentional ambition to supplant dialectical materialism with cybernetics. . . . If a hierarchy of control exists [in nature], then the question inevitably arises: Who is the chief controller? This can only be a force that does not depend on anyone or anything, in other words, a god. . . . Thus, in accordance with the logic of any idealistic trend [in philosophy], the conception of "controllers" of life phenomena leads to popery.[28]

The review ended with a suggestion to remove Liapunov from the editorship, prohibit the publication of biological articles in *Problemy kibernetiki*, and submit such articles instead to biological journals, conveniently controlled by the Lysenkoites. Alarmed by such serious charges, the director of the publishing house threatened to suspend the publication of biological articles in *Problemy kibernetiki* until the matter was resolved.[29]

Cyberneticians quickly mobilized the scientific community for the support of *Problemy kibernetiki*. Aksel' Berg made several dozen copies of the review and sent them to influential scientists and to the authors of the criticized articles. He received some 40 responses from leading Soviet scientists (including the biologists Vladimir Engel'gardt, Ivan Knuniants, and Vladimir Sukachev, the mathematicians Andrei Kolmogorov, Mikhail Lavrent'ev, and Sergei Sobolev, the physicist Igor' Tamm, and the economist Vasilii Nemchinov) vigorously defending the position of *Problemy kibernetiki*. Raisa Berg, who was among the accused authors, wrote in her response that the cybernetic approach in biology was "confirmed by practice," and defended the use of cyberspeak:

> [The review] speaks with contempt about the cybernetic language used by the authors of the reviewed articles. This contempt is unjustified. One of the goals of *Problemy kibernetiki* is to establish contact among specialists from different fields, which is helped by the elaboration of a common language.[30]

On the basis of these supportive letters, the Council on Cybernetics prepared a detailed rebuttal.[31] Aksel' Berg appealed to the Party Central Committee and to the presidium of the Academy of Sciences. He obtained permission to call a session of the Biological Division of the Academy in April of 1962. This session played a crucial role the legitimization of "biological cybernetics." A broad range of topics, from the "processing of information by the brain" to "self-regulation of processes in cells," were discussed. Berg opened the session, calling upon the participants to find "an optimal form of interaction between the possibilities of cybernetics and the needs of biology."[32] Academician Vasilii Parin—a full member of the Academy of Medical Sciences and the head of the medical section of the Council on Cybernetics—called on his colleagues to "work hard to prepare a large-scale introduction of cybernetics in biology, to redirect our thinking toward the cybernetic examination of biological issues."[33] At this session, the Lysenkoites were unable to provide any open opposition to "biological cybernetics." It was hardly coincidental that just a few days later, at the Party Central Committee's Plenary Session on Agriculture, Trofim Lysenko asked to be relieved of his duties as president of the Academy of Agricultural Sciences for reasons of ill health.[34] The cyberneticians' victory was far from complete: the Biological Division of the Academy remained under the control of the Lysenkoites. In their own disciplines, however, cyberneticians, mathematicians, computer scientists, physicists, and chemists could now safely shelter non-Lysenkoist biological research.

The Mathematical "Axioms of Life"

Soviet cyberneticians now viewed living organisms as belonging to their own professional domain and no longer to the exclusive realm of the life sciences. A new, cybernetic approach to biology, with its alluring promise of creating "thinking machines," acquired wide popularity among the young generation of Soviet scientists. In April of 1961, in a public lecture on

"Automata and Life" before a crowd of 1,000 that filled Moscow University's largest hall, Kolmogorov proclaimed:

> If such qualities of a material system as "being alive" or "capable of thinking" are defined in a purely functional way (for example, any material system with which it is possible to discuss meaningfully some problems of contemporary science or literature will be called a "thinking system"), then one would have to admit that in principle living and thinking beings can be *created artificially*. . . . I belong to the clan of those reckless cyberneticians who see no principal limitations on a cybernetic approach to the problem of life, and believe that one can analyze life in its entirety, including all the complexity of the human mind, with cybernetic methods.[35]

Soviet cyberneticians believed that cyberspeak was *the* language of science, and that rejecting this language meant giving up a scientific approach. At the 1958 philosophical conference, one Lysenko supporter accused Liapunov and Sobolev of reducing the notion of life to a circulation of information and argued that this transfer of terminology from one field to another was illegitimate.[36] Sobolev sharply replied that if one did not describe heredity as transmission of information, the only alternative would be to appeal to divine providence.[37]

Liapunov similarly understood the anthropomorphic terms of cybernetics as more than metaphors. He suggested calling any system that was highly stable and that maintained its stability by processing information encoded on a molecular level "alive." In his view, what made a system alive was not the material of which it was made, be it protein or DNA, but the organization and function of its elements.[38] In a 1962 joint article with the biologist Andrei Malenkov, Liapunov attempted to translate basic concepts and laws of genetics into the language of set theory, giving formal definitions of "intuitive" genetic concepts and strict mathematical formulations of the "postulates" of genetics.[39] In private correspondence, he described this work as a search for "the axioms of life."[40]

Despite his use of *Problemy kibernetiki* as a publishing venue and his earlier contributions to biophysics that inspired Schrödinger's *What Is Life?*, Timoféeff-Ressovsky remained somewhat skeptical about the revolutionary power of cyberspeak. He described Liapunov's cybernetics crusade with good humor: "Liapushka is a sweetie. With great enthusiasm, he would carry you along the wrong path; later, upon discovering his blunder, he would carry you along another path with no less enthusiasm than before, and this new path would be equally wrong."[41] Teasing Liapunov, Timoféeff-Ressovsky used the term *cybernetics* in their private letters in the sense of *confusion* or *mess*; he once described his having put a letter in the wrong envelope as a "complete cybernetics."[42] "Anybody who met with mathematicians more or less regularly," joked Timoféeff-Ressovsky, "can easily imagine the catastrophic picture of the world at the moment when our life and activity are mathematized."[43]

Despite his skeptical attitude, Timoféeff-Ressovsky's involvement in the cybernetics movement profoundly influenced his own research agenda. Timoféeff-Ressovsky did not merely insert a handful of cybernetic terms into his papers to get them published in *Problemy kibernetiki*; he took seriously Liapunov's call for "precise definitions" of biological concepts, and he made systematic attempts to reformulate biological theories in an "exact language" specifically "for cyberneticians." In a private letter to Liapunov in October of 1957, Timoféeff-Ressovsky wrote:

> I sat down and wrote for you, cyberneticians, [an article titled] "Microevolution." I tried, on the one hand, to cover everything essential, and on the other, to be brief. It came down to 33 paragraphs in an aphoristic-axiomatic style. It came out not bad, I think, quite original and different from other writings on evolution. All basic definitions seem to be sufficiently brief and rigorous.[44]

A few weeks later, Timoféeff-Ressovsky wrote to Liapunov about his intention to develop a set of strict definitions for the major concepts of genetics, in the same "aphoristic-axiomatic style," specifically "for cyberneticians and mathematicians."[45] While ridiculing the universalistic pretensions of cybernetics, Timoféeff-Ressovsky believed that cybernetic modeling could be very helpful in the study of specific biological systems. "Perhaps it would be better [for cyberneticians] to refrain from solving all global problems," he argued, "but instead jointly [with biologists] to attempt the construction of mathematical and computer models of simplified biocenological systems."[46] Timoféeff-Ressovsky wrote to Liapunov that the task of elaborating the basic principles of biological experiment would be "most suitable for mathematicians with a cybernetic slant."[47]

Liapunov and Timoféeff-Ressovsky saw their friendship as the starting point for a full-scale collaboration between cyberneticians and biologists. They believed that cybernetics not only supplied methods for "mathematical biology" (the construction and analysis of mathematical models of biological phenomena) but also served as the basis for a new approach to theoretical biology. Using the cybernetic notions of system and organization, Timoféeff-Ressovsky classified living nature into systems arranged

Figure 5.7
Nikolai Timoféeff-Ressovsky and Aleksei Liapunov in Miassovo. Courtesy of Natal'ia Liapunova.

hierarchically into four "levels of organization"—the cell, the organism, the population, and the biocenosis—with each system functioning as an element of a higher-level system.[48] Liapunov, in turn, interpreted these systems as cybernetic "control systems," each with its own mechanism of control and information exchange.[49] He argued that a unified theoretical perspective on the problems of life could be achieved "from the viewpoint of the theory of systems and control processes, that is, from the viewpoint of cybernetics."[50] In this case, cybernetics was called not so much to solve particular biological problems as to provide a discursive bridge between various biological disciplines. Cyberspeak was to become a common language for all biological disciplines, from molecular biology to developmental biology to evolutionary biology to ecology.

Liapunov's appeal was heard by the leading evolutionary biologist Ivan Shmal'gauzen, a prominent target of Lysenko's attacks at the July-August 1948 session of the Academy of Agricultural Sciences. By interpreting biocenosis as a control device with respect to populations, and thus representing evolution as regulated rather than a random process, Shmal'gauzen was effectively "translating Darwin's theory into the language of cybernetics."[51] In their introduction to a collection of Shmal'gauzen's papers on "biological cybernetics," Liapunov and Raisa Berg wrote:

> Shmal'gauzen did not stop at discovering the universality of the feedback principle at all levels of the organization of life, starting from the molecular level and up to the organism as a system. He also deserves credit for studying this principle at such levels of the organization of life in which the organism is included as a component, that is, at the levels of population and biocenosis. Evolution itself has appeared before us as a process regulated by feedback.[52]

While Liapunov attempted to translate classical genetics into cyberspeak, and Shmal'gauzen did the same for evolutionary theory, Liapunov's disciple, geneticist Vadim Ratner, wrote a dissertation on "genetic control system," bringing molecular biology under the umbrella of cybernetics. He introduced the notion of "genetic system" as "a set of cellular and molecular structures and mechanisms participating in the recording, transmission, implementation, and processing of genetic information," and defined the gene as a "compact set of hereditary memory locations (genetic elements) that encode discrete . . . genetic functions."[53] He considered genetic systems as "control systems" in Liapunov's sense, and described their operation in terms of memory mechanisms, information flows, and coding methods.[54]

Although some "biological cyberneticians" felt that the use of cyberspeak could sometimes be excessive, the cybernetic legitimization of genetics in the face of Lysenko's strong opposition seemed more important than putting exact limits on the cybernetic approach. Academician Vasilii Parin, who succeeded Liapunov as chairman of the Biology Section of the Academy Council on Cybernetics, warned that one "should not abuse cybernetic terminology," but in the same breath he described cells, organs, and organisms as "cybernetic systems" and called for the "mathematization and algorithmization of major biological parameters."[55]

The grand project of the "cybernetization" of Soviet science was sustained not only by the popular appeal of cyberspeak but also by the strategic advantage a marginalized scientific theory acquired when it was translated into the language of cybernetics. In this way, cybernetics helped legitimize not only genetics but also non-Pavlovian "physiology of activity."

Physiological Cybernetics: The Brain as a Subject of Technology

Cybernetics entered Soviet academic discourse at the time of a sharp debate between the orthodox followers of Ivan Pavlov's physiological school and their opponents. Cybernetics opened new vistas for physiological research, for it dealt with purposeful behavior, which had been bracketed out by the dominant dogmatic version of the Pavlovian doctrine. Cybernetics suggested parallels between nervous impulses and information exchange, between performing a movement and executing a program, and between thinking and computing. Cybernetics-minded physiologists were fascinated with the complexity and subtlety of the new man-machine metaphors. Orthodox Pavlovians, however, quickly dismissed such analogies as "mechanistic." To cyberneticians, on the other hand, such cybernetic self-regulating devices as computers and servomechanisms seemed much more appropriate as models for physiology than the telephone switchboard Pavlov had used as a metaphor for higher nervous activity. The struggle between orthodox Pavlovians (adherents of reflex theory) and "physiological cyberneticians" (advocates of circular physiological mechanisms) shaped the Soviet debate over the validity of cybernetic models in physiology.

One of the central tenets of cybernetics was the analogy between the computer and the human nervous system. In cyberspeak, both were described as information-processing devices. The analogy went both ways: from physiology toward technology (when neurophysiological knowledge was applied to build efficient devices) and from technology toward physiology (when technical terms and mathematical formalisms were employed to describe physiological processes). Mathematicians and engineers borrowed such common physiological and psychological concepts as *memory*, *homeostasis*, *reflex*, and *purpose* and attached strict technical meanings to them. Physiologists, on the other hand, reversed cybernetic metaphors and began using such concepts as *information*, *programming*, and *feedback* in a physiological context.

The prominent non-Pavlovian physiologist Nikolai Bernshtein was one of the first to take advantage of cyberspeak. While the Pavlovian school eschewed the notion of purpose, considering it purely psychological and therefore "unscientific," Bernshtein made that notion the centerpiece of his theory. He argued that the rigid Pavlovian scheme of conditional reflexes was based on experimental studies of animals confined in cages and subjected to measured stimuli, and that such studies depicted the organism as merely responsive, or "passive." He called for the creation of "physiology of activity," which would study purposeful behavior. Bernshtein insisted that a scientific physiological study of purposeful behavior was possible if the notion of purpose was conceptualized as "material codes in the central nervous system . . . such that both forecasts and programs of the future may be programmed into the nervous system."[56] In 1957 he published an article in which he systematically translated his theory of locomotion into the language of cybernetics. Instead of the "construction of movements," he spoke of "control" and "programming"; nervous impulses became "informations" (plural), and the motor apparatus was described as a self-regulating servomechanism.[57] The use of cybernetic instead of psychological terms made it possible to avoid accusations of "idealism" and "vitalism" such as had been brought against Bernshtein before. Bernshtein's "physiology of activity," it seemed, could only be written in the language of cybernetics.

Bernshtein borrowed his new vocabulary from Wiener's *Cybernetics*, but conceptually he did not depend on Wiener. Bernshtein found Wiener's model of purposeful behavior motivating, but he revised it immediately. Bernshtein argued that the goal of action was encoded in the nervous system as the model of a future event, and that purposeful behavior was oriented toward this model rather than toward an actual target.[58] Bernshtein eventually arrived at a comprehensive model of the organism as a self-regulating machine that received information from the external world, encoded it in a model, programmed its actions, and constructed its movements.[59]

Unlike Wiener, Bernshtein made a clear distinction between simple adaptation to the environment and purposeful activity aimed at changing the environment. The former could be achieved by means of Pavlovian reflexes; the latter could not be reduced to reflexes. To explain the mathematical meaning of this distinction, Bernshtein employed the conceptual apparatus of "well-organized functions" elaborated by mathematicians Izrail' Gel'fand and Mikhail Tsetlin of the Applied Mathematics Division.[60] Gel'fand and Tsetlin called multi-variable functions "well-organized" if their arguments could be separated into "essential" and "non-essential" variables. The former determined the main characteristics of a function (its overall shape and its extremes); the latter could cause only abrupt local changes and discontinuities but exerted little influence on the function as a whole. Bernshtein argued that the coordination of movements (for example, writing) and the construction of models in the brain in the process of perception could both be described by those "remarkable functions." A handwriting style, for example, could vary in its "non-essential" parameters depending on the position of a hand, but it still possessed "essential" features characteristic of a particular person. Bernshtein argued that living organisms acted just like "well-organized" mathematical functions:

> It has already been observed how differently an organism behaves under the influence of its surroundings with reference to essential and non-essential variables. As regards the latter type, it is reactive and, so to speak, yieldingly adaptable: if one leaf on a tree receives more food than another, then that leaf grows more vigorously than the other one. . . . But essential characteristics of structure and shape such as those which determine the plan of the flower . . . are only relinquished by an organism if it is subjected to very violent interference. . . . Thus the function, that is the organism, may be said to be reactive as far as its non-essential variables are concerned, but highly non-reactive, or active, with regard to its essential ones.[61]

By this distinction, Bernshtein also illustrated the limited applicability of the Pavlovian model (reactions of a passive organism) relative to his own model (actions of an active organism).

Bernshtein argued that such concepts as equilibrium and homeostasis were applicable only to non-essential variables. When, on the other hand, external influences affected an organism's essential variables, the organism would "respond with the most active counteraction and not yield without serious struggle, sometimes with the help of a counterforce, sometimes with evasive tactics."[62] Somewhere between the lines, Bernshtein may have reflected on the passive social tactics of the conformists who were "yieldingly adaptable" and looked for an "equilibrium" with the authorities. Personally, Bernshtein saw his mission as "liberating the organism from the role of a 'reactive automaton,'"[63]—in other words, liberating Soviet physiology from Pavlovian dogmas. Perhaps he used cyberspeak as a "counterforce" or an "evasive tactic" to defend his "essential variables."

Supporters and opponents of "physiological cybernetics" clashed in an open debate at the All-Union Conference on Philosophical Questions of the Physiology of Higher Nervous Activity and Psychology held in Moscow in May of 1962.[64] Speaking at the conference, Bernshtein argued that reflex theory, in both Cartesian and Pavlovian versions, treated the organism as a "highly organized reacting machine."[65] He contended that initial perceptions did not simply launch corresponding reflexes but were transformed by mathematical "operators" to form a well-structured mental "model of the world." Orthodox Pavlovians responded with an old argument against the use of mathematics in the life sciences; they charged that Bernshtein's "models of the world" were "detached from their material substance, that is, the nervous structures." Alluding to Lenin's "classical" critique of the "idealistic" interpretations of relativity theory in which "matter disappeared and only equations remained," one of the conference participants argued that in Bernshtein's theory "physiological processes in the brain are supplanted by the technology of mathematical thinking," "reflex mechanisms of the functioning of the nervous system totally disappear" and "only mathematical transformations remain."[66] While Wiener claimed that the cybernetic model of purposeful behavior had bridged the gap between mechanical causality and teleology, Soviet critics accused Bernshtein both of "mechanicism" (i.e., reducing everything to mechanical causality) and of teleology (which the critics closely associated with vitalism and idealism). Criticizing Bernshtein's notion of the "inborn program of development," one speaker asked rhetorically: "Who compiled this program and put it into living matter, like in a cybernetic machine? There is a strong smell of Aristotle's entelechy here."[67]

Cyberneticians provided crucial support for Bernshtein's position. They claimed that the dominant physiological doctrine was inadequate, for it did not provide a clear picture of physiological mechanisms. For example, the engineers Artobolevskii and Kobrinskii argued that contemporary theories of human thinking lacked foundation and were nothing more than conventions. They wrote: "It is necessary to understand how man thinks, to understand the whole mechanism of his thinking in its entirety—to understand and not just agree that we would call thinking such-and-such!"[68] Speaking at the 1962 conference, the leading specialist in pattern recognition, the mathematician Mikhail Bongard of the Institute of Biophysics, argued that Pavlovian reflex theory, if subjected to a cybernetic test, failed to explain pivotal physiological mechanisms, such as learning:

> If you claim that you understand the mechanism of learning, this can easily be checked. Engineers will create elements that would be able to acquire conditional reflexes. Try to assemble from such elements a device that would act expediently in a complex changing environment. I have studied this problem myself and learned that it is hopeless to try to assemble such a device from the elements modeling conditional reflexes.[69]

Bongard argued that reflex theory was clearly not adequate for explaining higher nervous activity. According to the Pavlovian doctrine, a conditional reflex can be established only on the basis of an unconditional one, by means of substituting an unconditional stimulus with a conditional stimulus. Bongard contended, however, that complex reactions, such as solving an arithmetical problem, could not be caused by any unconditional stimulus, and therefore there was nothing to substitute for. "Even a system of very complex conditional reflexes would not suffice to explain the activity of a living organism," he maintained, "in the same way as statics cannot explain the flight of a rocket."[70] Instead, Bongard argued, one must look for a solution by building cybernetic models. He suggested a feedback model of learning, implemented in his original computer program for pattern recognition; this program derived its own rules of classification by "learning" from the existing examples of correct classification.[71]

Physiology was among the first disciplines included by Liapunov in his grand project of the cybernetization of science. Among the specific cybernetics problems in the field of physiology, he listed the following:

(1) the study of information flows in the nervous system and the receptors;
(2) the study of the methods of encoding information in the nervous system and the receptors;
(3) the study of reactions, reflexes, and behavior of animals;
(4) the evaluation of the amount of information and the channel capacity of the nervous system;
(5) the study of hierarchical functioning and collective behavior;
(6) the algorithmic description of the nervous system and the receptors.[72]

To set an example of a successful translation of physiological concepts into cyberspeak, Liapunov offered a stochastic algorithm modeling the acquisition of a conditional reflex.[73]

On the pages of *Voprosy filosofii*, the control engineer Gal'perin announced that "automatic control systems in today's machines fulfill the function of a nervous system."[74] He claimed that automatic control devices were already capable of demonstrating unconditional reflexes, since they gave preset responses to diverse inputs. He further argued that conditional reflexes, too, could, in principle, be reproduced in modern control devices. "Taking the exact sense of Pavlov's definition [of the conditional reflex]," he wrote, "it is impossible to make a distinction between the mechanism of the conditional reflex and the functioning of an automatic control system."[75] He concluded that automatic control devices were bringing about a "reevaluation of physiological values."[76] This cybernetic "expansionism" left little room for non-cybernetic physiology. Paraphrasing Pavlov's contention that the human brain, which had created natural science, was itself becoming a subject of natural science, Gal'perin wrote: "The human brain, which has created technology, now, in control devices, is itself becoming (in its simplest functions) a subject of technology."[77] If the human brain became a subject of technology, what would be the subject of neurophysiology?

Speaking at the 1962 conference, Bongard announced that cybernetic models would henceforth be "unrelenting examiners" of physiological theories and hypotheses. When cyberneticians assumed the role of judges of physiological theories, the orthodox Pavlovians had little chance to retain their dominant position in the physiology community.

"Man Is the Most Perfect of All Known Cybernetic Machines . . . "

Soviet "physiological cyberneticians" aimed at a comprehensive cybernetic modeling of physiological processes. Bernshtein, for example, criticized Western cyberneticians' experiments with devices simulating individual physiological acts, and called for creating universal cybernetic models that would cover a wide range of physiological functions. A cybernetic model would adequately represent human physiological mechanisms, he argued, only if it demonstrated human-like variations of quality and accessibility over a wide range of functions.[78] Cyberneticians therefore aspired to a complete translation of physiological terminology into cyberspeak. Sobolev, in particular, argued that there was no limit to the applicability of notions of cybernetics to living organisms:

> In cybernetics, a machine is defined as a system capable of accomplishing actions that lead to a certain goal. Therefore, all living organisms, and human beings in particular, are in this sense machines. Man is the most perfect of all known cybernetic machines. . . . There is no doubt that all human activity manifests the functioning of a mechanism, which in all its parts obeys the same laws of mathematics, physics, and chemistry, as does any machine.[79]

Pavlovian physiologists tried to oppose this trend, but they could hardly resist the thrust of the cybernetics wave. For example, Iurii Frolov argued that a machine "lacks feedback that exists between man and the constantly changing social environment" and therefore cannot think.[80] Ironically, while trying to show the limitations of man-machine metaphors, he himself borrowed the term *feedback* from the language of cybernetics. Man-machine metaphors permeated public discourse so deeply that it proved impossible to step outside cyberspeak even for the sake of criticizing this metaphorical language.

The use of cyberspeak among reform-minded Soviet physiologists was becoming truly pervasive. In the contemporary scientific literature, one finds many such examples, such as the following:

> Speaking in the language of mathematical cybernetics, the synapse is characterized by indefinitely wide probabilities of change.[81]

> If we use the cybernetic language, we can speak of a gigantic amount of information passing through generations in the course of morphogenesis.[82]

Bernshtein argued that cyberspeak played a more important role in the latest revolutionary transformation of the life sciences than new scientific instruments or computing devices:

> The main reason why mathematics and biology finally began to find a long-awaited common language was undoubtedly the formation and elaboration of new concepts and generalizations. Such concepts include *control, information, coding, communication,* and *multi-level regulation,* in other words, precisely the circle of ideas that is covered by the term cybernetics.[83]

The reversibility of man-machine metaphors facilitated an exchange of ideas between cybernetic physiology, engineering, and mathematics. Bernshtein wrote, for example, that an organism encountering a "dynamically variable" situation would have to make "a probabilistic forecast": "To use a metaphor, we might say that the organism is constantly playing a game with its environment, a game where the rules are not defined and the moves planned by the opponent are not known."[84] The mathematician Mikhail Tsetlin, a close friend of Bernshtein, translated this idea into the language of game theory.[85] He studied a particular type of game in which stochastic automata did not "know" the pay function of their game in advance and had to develop their tactics in the course of the game. Tsetlin informally compared the tactics of a simple automaton facing complex environment to the behavior of "a little animal in the big world."[86]

Tsetlin studied finite automata, the same simple mathematical objects that attracted the attention of John von Neumann, but focused specifically on their "collective behavior." Tsetlin proposed a general mechanism by which the combined action of a large number of primitive automata, each following very simple rules, resulted in expedient actions of the system as a whole. The key to this mechanism, he argued, was "the principle of least interaction": all parts of the system "strove" to minimize their interaction with other parts and with the system's environment. This mechanism greatly simplified the function of control, since the actions of each part no longer had to be directed from one center. Given a "pay function," individual automata figured out their own best strategies, which resulted in the overall optimal strategy for the system. Neurophysiologists usually assumed that various nervous centers in the brain coordinated their activity by means of a complex system of connections. Tsetlin argued that, overall, expedient behavior could be achieved even if these centers "interacted" only by means of observing changes in their environment:

> At each moment, the subsystem solves its own "particular," "personal" problem—namely, it minimizes its interaction with the medium; therefore, the complexity of the subsystem does not depend on the complexity of the entire system. . . . Our mathematical models allow us (to a certain degree) to imagine the interaction of the nerve centers without considering the complex system of links and the coordination of their activity.[87]

The works of Tsetlin and Bernshtein straddled the fence between mathematics and neurophysiology. They did not easily fit in the accepted frameworks for either discipline. They found a niche in cybernetics. Tsetlin became the first "Learned Secretary" of the Academy Council on Cybernetics on the day of its inception. Both Tsetlin and Bernshtein actively published their results in *Problemy kibernetiki*, edited by Liapunov.

Legitimized as "physiological cybernetics," Bernshtein's methods of the study of locomotion were widely applied in ergonomic studies and in the training of cosmonauts. For example, using Bernshtein's methods, his student Levan Chkhaidze worked out a quantitative measure of the coordination of motor actions and was able to prove that this coordination would be quickly restored after some initial disturbance caused by changes in the gravitational field. This result dispelled some fears among Soviet space researchers about the reliability of cosmonauts' motor actions in the conditions of weightlessness.[88] In 1967 a collection of Bernshtein's articles was translated into English[89] and propagandized by a group of physiologists at Haskins Laboratories in New Haven, Connecticut; his work "rapidly became a sort of bible for those who considered him as a 'laboratory genius.'"[90] In 1984 leading Western specialists called Bernshtein "a precursor of cognitive neurobiology."[91]

Soviet cyberneticians believed that mathematical modeling and computer simulation would reveal the underlying mechanisms of all brain functions, including linguistic abilities. The Council on Cybernetics set up a Linguistics Section, which provided a safe haven for innovative research marginalized by the mainstream Soviet linguistics.

Cybernetic Linguistics: Making the Study of Language an "Exact Science"

In the mid 1950s, a new generation of Soviet linguists, repelled by the opportunistic turns taken by the linguistics establishment during the period of Marrism and during the subsequent anti-Marrist campaign, was searching for a new research paradigm. The linguist Viacheslav Ivanov, then an assistant professor at Moscow University, later recalled: "We were tired of the phraseology of the official philosophy. We wanted to deal with precisely defined concepts and with terms that were defined through rigorously described operations."[92] The linguist Isaak Revzin, of the Institute of Foreign Languages, expressed "distrust of all kinds of sociological phraseology and linguistic journalism" and called for the elaboration of "objective, exact methods" of linguistics.[93] The cultural historian Iurii Lotman, of Tartu University, admitted that his "tiredness of the verbiage that is sometimes introduced under the name of science" drove him to use "exact methods" of study.[94] These scholars saw the sought-after "exact language" of science in the formal language of cybernetics and information theory.

A major part in the promotion of cybernetic ideas in Soviet linguistics was played by Roman Jakobson, the Russian-born American linguist whose works were discussed in chapter 1. His early involvement in the Formalist movement in the 1910s and the 1920s was also characterized by the search for "precise terminology," in contrast to the rhetorical trend that dominated the humanities at the time. "Until recently, the history of art, particularly that of literature, has had more in common with causerie than with scholarship," Jakobson wrote in 1921. "In causerie we are slipshod with our terminology; in fact, variations in terms and equivocations so apt to punning often lend considerable charm to the conversation."[95] To turn linguistics into science, Jakobson adopted the structural approach, which, he argued, was dominating contemporary science. Like "any set of phenomena examined by contemporary science," he argued, language must be "treated not as a mechanical agglomeration but as a structural whole," and the basic task of structural linguistics was "to reveal the inner, whether static or developmental, laws of this system."[96] In the late 1940s, Jakobson joined the cybernetics circle around Norbert Wiener and Claude Shannon, and soon he brought the gist of cybernetic innovations to the Soviet Union. In May of 1956, during his first visit to Moscow after his emigration, Jakobson met informally with a number of young Soviet scholars, including Ivanov, and discussed applications of information theory to the analysis of language.[97]

In June of 1956, soon after Jakobson's visit, Ivanov and another young assistant professor at Moscow University—the mathematician Vladimir Uspenskii, a former student of Andrei Kolmogorov—decided to organize an interdepartmental research seminar on mathematical linguistics. They drafted a list of seminar discussion topics that included statistics, mathematical logic, machine translation, information theory, mathematical definitions of grammatical categories, and the "mathematization of language."[98] Uspenskii later recalled that he and his colleagues were driven by "the irrational urge to find in language precise laws that would resemble mathematics in their rigor."[99] An agenda for the "mathematization" of Soviet linguistics was set.

The seminar, which opened in September of 1956, attracted a mixed audience of mathematicians and linguists—unusual for both disciplines. At the first session, Uspenskii proposed to discuss two problems formulated by Kolmogorov himself: how to give formal definitions of the grammatical case and of the iambic poetic meter. It was no accident that the seminar started off with definitions: mathematicians were not content with the intuitive meanings of linguistic categories, to which linguists were accustomed. The mathematicians proudly claimed that striving for unambiguous definitions was one of the "specific traits of the mathematical style of thinking," and they insisted that a mathematician in linguistics "plays the role of a litmus test: if a definition satisfies the mathematician, then it must satisfy everyone."[100] In 1957 Uspenskii taught an extracurricular mathematical course for linguists in which he emphasized such principles of mathematical thinking as "clear explication of major abstract concepts, delineation between the definable and indefinable, [and] between the deductive and the inductive"—the principles that, in his view, linguistics students particularly lacked.[101]

Cybernetics, with its promise of making scientific knowledge objective by translating it into the "exact" mathematical language of computer algorithms, naturally appealed to the young generation of Soviet linguists. In the mid 1950s, the forbidden fruit of cybernetics, still labeled in the popular press a "reactionary pseudo-science," seemed particularly attractive to those dissatisfied with both political and scientific orthodoxy. In the autumn of 1954 Aleksei Liapunov's lecture on cybernetics at the Philology Faculty of Moscow University ended with a scandal: Liapunov was ejected from its

room for sowing ideological heresy. This only added to Liapunov's popularity, and soon he was asked to speak on the prospects of machine translation at the Moscow State Pedagogical Institute of Foreign Languages. Revzin, who attended the lecture, later recalled:

> He did not talk much about machine translation, but said only a few words in the end. [Instead] he spoke of Cybernetics (I heard this word for the first time!) from a broad philosophical perspective. The romance of the earliest stories of the fantastic prospects of cybernetics . . . shrouded the figure of Liapunov, who already looked like a preacher, in an aura of a pioneer. He linked the question of translation, which had been haunting me since my student years, with the entire host of complex human problems, from genetics and medicine to control, and this convinced me right away. I instantly decided that this was the way to go.[102]

Inspired by the promise of cybernetics, linguists began translating their problems into cyberspeak. They viewed the computer processing of texts as a model for understanding linguistic phenomena. In a 1961 article on "linguistic problems of cybernetics," co-authored with the prominent linguist Sebast'ian Shaumian, Ivanov argued that "the parts of the brain engaged specifically in the analysis of language can be compared to those specialized [computing] machines that are designed for linguistic analysis."[103] Ivanov also used machine translation as a model for analyzing various deviations from the norm in the human use of natural language:

> One can compare deviations from the linguistic norm that occur in machine-produced texts . . . to non-normalized human discourse (such as dialects, children's talk, or poetic speech) or to pathological deviations from the linguistic norm (aphasia). In the case of aphasia, one finds errors linked to the limitations on the capacity of short-term memory, which is typical of machines. . . . The literal interpretation of idioms, often observed in aphasia, is comparable to similar mistakes in machine translation, when each word in an idiom is simply linked to a corresponding dictionary entry, but this entry does not mention that this word may be part of an idiom.[104]

Ivanov and Shaumian called for a far-reaching reform of linguistics on the basis of mathematical formalisms and computer modeling. A new discipline of structural linguistics, they argued, must be built as an "abstract theoretical discipline studying the construction of formal models of language."[105] Ivanov and Shaumian viewed cyberspeak as a discursive "bridge" between structural linguistics and cybernetics:

> The basis of cybernetics is the study of the laws of transmission and processing of information. . . . In the transmission of information, it is often necessary to convert information from one sign system into another, that is, from one code into

> another. This type of conversion is called coding. Any code is a language, and coding is nothing else but translation from one language into another. Therefore, studying codes and coding is a linguistic problem, and the theory of codes and coding is a linguistic theory. . . . It is precisely the concepts of code and coding that serve as a bridge between structural linguistics and cybernetics.[106]

While Jakobson viewed natural language as a code, and therefore included linguistics under the umbrella of information theory, Ivanov and Shaumian regarded any code as a language, and thus portrayed information theory as part of linguistics. In any case, cyberspeak as a mediating language seemed to be applicable both to the human use of natural language and to the computer processing of texts. Ivanov and Shaumian proclaimed that structural linguistics belonged to the "complex of sciences united by cybernetics into an integrated ensemble."[107]

Fashioned as "mathematical" or "cybernetic" linguistics, structural linguistics as a discipline claimed its conceptual independence from traditional linguistics. "Mathematical linguistics is a mathematical discipline," Liapunov argued. "It has the same relationship to mathematics as does mathematical physics, which borrows its problems from physics and its methods from mathematics. . . . For a mathematician, it is part of mathematics; for a physicist—part of physics."[108] Revzin similarly defined mathematical linguistics as a "mathematical discipline aimed at a humanist subject," and modern structural linguistics as a "humanist discipline, which uses exact methods," and argued that the two overlapped and interacted significantly. In his view, structural linguistics, by using "exact methods" borrowed from mathematics, would incorporate "all the means of exact description of language."[109]

Inspired by mathematicians, structural linguists began to fashion their discipline after axiomatic mathematical theories. At a 1959 conference on mathematical linguistics, Shaumian proposed to reconstruct all of linguistics as an abstract, purely deductive science, whose concepts and laws were to be postulated a priori rather than discovered empirically.[110] In his 1962 book *Models of Language*, Revzin similarly suggested that linguistics be built as a formal axiomatic theory modeled on logic and mathematics:

> In its deductive part, Linguistics, it seems, can be constructed just as Logic or Mathematics are constructed; a certain minimal quantity of primary indefinable terms is established, and all the rest of the terms are defined by means of the primary ones. At the same time certain primary statements as to the connections between these terms (axioms) should be clearly formulated and all other statements should be proved, i.e. reduced to certain other statements.[111]

Instead of accepting the dominant view of linguistics as an ideology-laden humanist discipline, Soviet structural linguists preferred to think of themselves as natural scientists. "We were attracted by the precision of formulations [in mathematical linguistics]," recalled Ivanov. They believed that precisely formulated linguistic hypotheses, unlike claims made in the humanities, were verifiable: "In linguistics one could compare a theoretical statement with empirical data and to either confirm or reject it."[112] In their 1961 article, Ivanov and Shaumian argued that, through an alliance with cybernetics, structural linguistics would become an "exact science":

> The emergence of structural linguistics signifies a revolution in the study of language, resulting in its transformation from an empirical and descriptive field of knowledge into an exact one. Through structural linguistics, the study of language enters the family of exact sciences, such as physics, chemistry, and biology.[113]

By adopting cyberspeak, structural linguists began to associate scientific objectivity with formal definitions and with mathematical and logical models. Shaumian maintained that structural linguistics must be based on the methodological principles "imperative for any scientific theory as a logical system." One such principle, which he called "the principle of homogeneity," prescribed that "scientific explanation within the framework of a certain theory cannot rely on facts lying outside the subject of this theory."[114] The call to build linguistics as a formal logical system was an implicit attack on the pseudo-Marxist ideological considerations that played a prominent role in the dominant Soviet linguistic discourse. Revzin similarly attacked traditional linguists for using imprecise, "subjective" language. Such fundamental linguistic notions as *meaning*, he argued, could be "objectively" defined only through formalization. "Where there are no means of formalization, there is scope for any subjective structure," he maintained. "Only with the presence of clear formal rules for the establishment of identity of meaning is there a guarantee against subjectivism."[115] Revzin also argued that "the existence of more than two hundred different definitions of the term *sentence* makes it impossible to develop [a theory of] syntax on rigorous deductive principles and shows that the definition of basic linguistic units must be approached differently."[116] Revzin particularly attacked definitions (typical of Soviet traditional linguistics) such as "a sentence is a more or less completed thought," and he proposed to formulate a new definition in terms of set theory.

The final arbiter of formal logical consistency of linguistic theories was, of course, the "objective" computer. Mathematicians left no doubt that linguistic theories must pass a computer test. Kolmogorov, in particular, viewed computer modeling as a filter sorting out speculative theories:

> Work in computer translations yields interesting results, in particular for people designing computers and is especially interesting to linguists who, in the process of this work, are forced to specify their formulations of the laws of language. . . . Now it is impossible to use vague phrases and present them as being "laws," something that unfortunately people working in the humanities tend to do.[117]

Structural linguists also believed that only by making their theoretical concepts understood by a computer could they bring linguistics closer to the level of rigor and objectivity exemplified by mathematics. Ivanov's student Igor' Mel'čuk put forward a new "guiding criterion" for introducing linguistic concepts: the possibility of implementing those concepts on a computer. He argued that in this case these concepts would be defined "in a *purely formal* fashion, that is, with unambiguous and logically consistent formulations that do not require any additional information." "*Formal* equals *scientific*," he proclaimed.[118] Having begun his work in the area of machine translation, Mel'čuk later used the formal approach and the conceptual apparatus developed in this field to create an original linguistic theory.

From Machine Translation to Linguistic Theory

Structural linguistics, shunned by the Soviet linguistics establishment, found a place under the institutional umbrella of cybernetics in the field of machine translation. In the second half of the 1950s, Liapunov organized a machine translation group at the Applied Mathematics Division; Ivanov led a similar group at the Institute of Precise Mechanics and Computer Technology; the Institute of Foreign Languages established the Laboratory of Machine Translation, headed by Viktor Rozentsveig; and the Laboratory of Electromodeling, headed by Lev Gutenmakher, created groups of mathematical linguistics and mathematical logic in which both Ivanov and Uspenskii worked part-time. Soviet structural linguists did not merely find a refuge in the field of machine translation; their institutional cooperation with cyberneticians, mathematicians, logicians, computer programmers, and engineers resulted in profound conceptual innovations. Unable to solve practical problems of machine translation because of the acute shortage of computer time, structural linguists focused on theoretical problems of linguistics. They effectively used the conceptual and mathematical apparatus of cybernetics to address some traditional linguistic problems and to create new formal models of language.

In September of 1954 the director of the Institute of Scientific Information, Dmitrii Panov, published in a Soviet mathematics review journal a brief note about the first public demonstration of Russian-English machine translation, which had taken place in January of that year at IBM's Technical Computing Bureau in New York.[119] This report attracted the attention of Soviet authorities, who immediately launched a determined effort "to catch up with the Americans" in this important research area.[120] Recognizing the great potential value of automated translation for intelligence, the KGB set up a special unit to develop a computer system for English-Russian translation. Panov was enrolled as a consultant on this project.[121] Soon after being appointed Deputy Director of the Institute of Precise Mechanics and Computer Technology, he organized a machine translation group there. In late 1955 the group used the BESM computer to test the first version of their English-Russian translation program. Panov professed a pragmatic approach, and placed emphasis on efficient computer algorithms and large computer dictionaries. Instead of trying to do a complete grammatical analysis of the translated text, Izabella Bel'skaia, the leading linguist in the group, developed a set of "linguistic schemes" (ad hoc rules of word-for-word translation). "A study of linguistic structures may be interesting from many different viewpoints," Panov argued, "but from the point of view of translation, such a study seems to be directed at issues of secondary importance and actually distracts from solving main problems."[122]

Liapunov's group in the Applied Mathematics Division took an opposite approach to the problem of machine translation.[123] Liapunov viewed machine translation as a "beyond the clouds" problem: it was impossible to solve completely in practical terms, but it could help generate interesting research projects in computational mathematics and in linguistics. "The development of machine translation," he wrote, "requires a productive use of both linguistic and mathematical-cybernetic methods and often raises substantial questions in both fields."[124] Under Liapunov's guidance, the linguist Igor' Mel'čuk, then an undergraduate at Moscow University, and the mathematician Ol'ga Kulagina, Liapunov's graduate student, designed an algorithm for French-Russian translation of mathematical texts, and the linguist Tat'iana Moloshnaia developed an English-Russian translation algorithm. Liapunov's group devoted much time to the elaboration of general rules of syntactic analysis and synthesis and introduced the concept of "elementary grammatical configurations," which later proved useful in theoretical linguistics.

Liapunov and his colleagues strongly criticized Panov's narrow utilitarian approach and argued that Panov's claims of having achieved machine translation were grossly exaggerated. Panov's hopes for receiving a State Prize were not fulfilled; Moloshnaia wrote later that Panov and Bel'skaia were "publicly exposed, and their results were recognized as false."[125] The conflict between the two groups was not only intellectual but also political. Mel'čuk asserted that Panov was "just an administrator, a loyal Party member," not than a scientist.[126] While Panov was collaborating with the KGB, Mel'čuk's nonconformist political activities were attracting professional attention of the same organization. He was banned from entering the premises of the Institute of Foreign Languages (which trained translators for the KGB), and he had to use a nearby café to meet with linguists working at that institute's Laboratory of Machine Translation.[127] As several leading Soviet structural linguists faced political troubles, their use of machine translation as a cover for structural linguistics research became all the more urgent. In late 1958 Party activists at Moscow University attacked Ivanov for maintaining close links with Roman Jakobson and with the novelist Boris Pasternak. Ivanov's superiors at the Philology Faculty charged that "Ivanov had declared his disagreement with the judgment of the Soviet public and Party activists concerning the anti-Soviet novel *Doctor Zhivago* by Pasternak," and that he had arranged a meeting between Pasternak and Jakobson, whom they labeled "a traitor to his motherland." Ivanov's references to Jakobson's work were regarded as open propaganda for an alien ideology:

> Ivanov by all means supports and popularizes Jakobson's works at international conferences and in the Soviet press. Such personal contacts with and apologetic attitude toward the ideas, conceptions, and the persona of Jakobson, an enemy of Marxism, are incompatible with the dignity of a Soviet patriot scholar.[128]

Intellectual marginality and political nonconformity of structural linguists were closely intertwined. As an innovative researcher and a political emigrant, Jakobson posed a challenge both to the dominant trend in Soviet linguistics and to the ideological dogmas expounded by Soviet science administrators. Ivanov's disagreement with dominant scientific views sowed political discord; conversely, political complications engendered professional marginalization. In December of 1958 Ivanov was fired from Moscow University and lost his position as Deputy Editor-in-Chief of *Voprosy iazykoznaniia* [*Problems of Linguistics*]. Mel'čuk and several other linguists protested Ivanov's dismissal and were forced to leave the university.[129] Unable to find a job in any linguistics institution, Ivanov eventually was hired to lead the machine translation group at the Institute of Precise Mechanics and Computer Technology.

Knowing that the authorities would be more supportive of computer systems with practical outcome than of purely theoretical innovations, structural linguists began to make claims that formal methods in linguistics would pave the road to machine translation. Ivanov later admitted that the discourse of "cybernetic linguistics" often served tactical purposes:

> I cannot say that we intentionally deceived anyone, but it is now impossible to overlook the fact that in those past discussions the practical utility of new methods was if not strongly exaggerated then at least strongly emphasized. Society oriented itself toward pragmatic tasks, and the authorities were willing to allow anything that advanced those tasks. Everybody knew the rules of the game. And we yielded to [the spirit of] the time.[130]

The authorities indeed showed great interest in machine translation, but the bulk of their support went to the special research unit set up by the KGB, whose work remained classified through the 1960s.[131] In academic institutions, the situation with machine translation in the Soviet Union resembled a popular Soviet-era joke: "First learn how to swim, and then we'll fill the swimming pool with water." Liapunov's group at the Applied Mathematics Division, for example, could use only 5 minutes of computer time per week, and translating one sentence on the STRELA computer took about 3 minutes.[132] The position of Ivanov's group at the Institute of Computer Technology was even worse. In the late 1950s, all the researchers at that institute were allowed to use only 5 hours of computer time per week at the Computation Center of the Academy of Sciences. Because of the shortage of computer time, the machine translation group, which was considered of secondary importance within the institute, barely had any access to computers.[133] Another leading specialist in machine translation, Isaak Revzin of the Institute of Foreign Languages, one of the co-authors of *The Fundamentals of General and Machine Translation*, saw a computer—from a distance—only once in his lifetime.[134] By the mid 1960s, Soviet structural linguists proposed "to view machine translation at the current stage as a *theoretical* rather than practical problem."[135]

Structural linguists, who were interested in theoretical linguistics much more than in machine translation in the first place, used this lack of access to working computers to shift the emphasis from machine translation programs to general linguistic models. Soviet linguists argued that machine translation could serve as an experimental base for their theories:

> Machine translation and, generally, automatic analysis and synthesis of texts acquire special significance for linguistics: they provide experimental confirmation of linguistic statements and data. Previously, linguistics included only experimental phonetics, now one can watch the emergence of experimental morphology, experimental syntax, and—what is particularly important and promising—experimental semantics.[136]

However, when structural linguists spoke of "experiments" they usually meant only the theoretical possibility of constructing a computer algorithm, rather than actual computer runs. Obtaining scarce computer time for testing linguistic theories was usually out of the question. Soviet research on machine translation was more of a thought experiment in which the implications of imaginary computer modeling were explored. Machine translation studies often provided models and metaphors for theoretical linguistics, rather than new experimental data.

In cybernetic linguistics, fundamental and applied research switched their traditional roles: machine translation became a vehicle for theoretical linguistics. "Applied linguistics" now applied itself to solving theoretical problems. Referring to machine translation, Ivanov wrote: "This area of applied linguistics so far has been applying itself to linguistics proper by fostering its transformation into an exact science and by providing criteria for testing and selecting models of language."[137]

While being transformed into an "exact science," structural linguistics departed further and further from traditional linguistics. At the 1958 conference on machine translation in Moscow, the Leningrad linguist M. I. Steblin-Kamenskii argued that the attempts to formalize language for the purposes of machine translation would demonstrate that "the same linguistic fact can be described in different ways, depending on definitions; and therefore all linguistic dogmas should be reconsidered"; in particular, he called for a comprehensive critique of "all traditional grammatical concepts such as *sentence*, *parts of the sentence*, and *parts of speech*."[138]

Igor' Mel'čuk, who despite his low administrative status was regarded by colleagues as an "informal leader" of Soviet structural linguistics, led an attack on traditional concepts of linguistics.[139] In particular, he criticized such common terms as *a stable word combination* and *an idiom* as vague. Instead, Mel'čuk proposed a quantitative measure of the stability of word combinations: only those word combinations whose degree of stability exceeded a certain threshold of probability would qualify as "stable." Similarly, he suggested a quantitative measure of "idiomaticity" that would reflect the rarity of the meaning of each word in an idiom. Unlike the "vague" traditional concept of the idiom, this new definition worked well for machine translation:

> This definition . . . makes it possible to construct translation dictionaries automatically. In order to do that, a computer must store parallel texts in two languages and rules for establishing correspondences between elements of these texts. Guided by this definition, the machine would be able to distinguish free combinations from idioms and to create lists of the latter.[140]

Mel'čuk deliberately based his definitions on procedures that in principle could be performed automatically by a computer. In his view, language operated by rules similar to computer algorithms: "Language . . . is a mechanism (that is, a system of rules) that transforms a given meaning into a text and also extracts meaning from a given text."[141] Therefore, if a linguistic theory was to be precise, it had to be rigorous enough to be translated into a set of computer algorithms. Mel'čuk proposed to "describe language not formally, but rigorously, so that a mathematician working together with you could then formalize [this description] independently."[142] Mel'čuk and his collaborator Alexander Zholkovsky put forward the goal of creating a working logical machine that would imitate the human use of language:

> It seems natural to consider the central task of linguistics to be *the creation of a working model of language*, a logical device which, operating on a purely automatic basis, would be capable of imitating human speech activity. This device should be thought of as a system of data and rules, which comprise, so to speak, the grammar or the "handbook" of language, its "working" description, which in principle can be implemented in a computer program. . . . The speaker has a certain meaning in mind and constructs a corresponding text, while the listener receives a certain text and extracts meaning from it. Language here functions as a mechanism in the full meaning of the word, namely, as a device for the transformation, "meaning—text—meaning."[143]

In the mid 1960s, Mel'čuk and Zholkovsky began working on "Meaning—Text," a formal model of linguistic competence based on the principles of machine translation.[144] Initially, they viewed this model as the prototype for an actual English-Russian translation program. They suggested a special "basic" semantic language to express the meaning of the original text. In their view, machine translation would involve three steps: "a transition from English to Basic English (independent meaning-oriented translation); a transition from Basic English to Basic Russian (translation proper); and a transition from Basic Russian to the idiomatic Russian (independent meaning-oriented synthesis)."[145] Lacking access to a computer, Mel'čuk and Zholkovsky were unable to implement the "Meaning—Text" model as a machine translation program. Instead, they began to view this model in a more theoretical light: as a model for linguistic competence in general.[146] They realized that a transition from text to meaning occurs not only in the translation from one language to another but also in the production and understanding of texts in the same language. Mel'čuk and Zholkovsky interpreted formal rules of morphological, syntactic, and semantic analysis and synthesis not just as elements of a machine translation program, but as components of a new linguistic theory.

The "Meaning—Text" model/theory postulated a special "semantic language" that expressed the meaning of a given text. The basic alphabet of this language consisted of elementary semantic units, or "atoms of meaning." Mel'čuk and Zholkovsky defined a set of formal rules of semantic analysis that expressed the meaning of a given text in an ensemble of alternative "semantic representations," reflecting possible ambiguities in the text. Similarly, formal rules of semantic synthesis translated a given semantic representation into a set of synonymous texts. Mel'čuk and Zholkovsky also developed a set of "semantic axioms," or "universal laws of reality," such as "Any action entails the undesirable loss of part of the actor's resources" or "People usually want more than they are entitled to."[147] This "semantic language" thus functioned as a formal axiomatic system. In Mel'čuk's view, this language could be compared to Leibnitz's *Lingua mentalis*, a universal language of thought.[148]

The "Meaning—Text" model implemented an original method of expressing the same meaning in different ways by using not only lexical synonyms but also other linguistic tools of synonymy—an idea originally developed by Zholkovsky and his colleagues in machine translation research.[149] Zholkovsky and Mel'čuk elaborated a procedure of "multiple" synthesis that combined lexical and syntactic variations and produced a large number of synonymous variants of translation (ideally, all possible ones) and then "filtered out" those that were unacceptable. The procedures of analysis and synthesis of natural-language texts, developed initially within the framework of machine translation, thus became incorporated into linguistic theory. Curiously, both meanings of the word *model* were present here: what began as an attempt to build a working model (a prototype) of a machine translation program later became a tool for understanding language, then was seen as the only objective representation of linguistic theory, and eventually played the role of theory itself—a model (an imitation or representation) of human communication.

Ideas and concepts of cybernetics, especially information theory, played an important role in the formation of the "Meaning—Text" model. At first, Zholkovsky and Mel'čuk could not find a rigorous definition for the most crucial concept in their model, the concept of meaning, and wrote that "meaning should perhaps be considered an indefinable concept."[150] Through Roman Jakobson, however, Soviet linguists were introduced to Claude Shannon's definition of information as "that which is invariant under all reversible encoding or translating operations"—in other words, as "the equivalence class of all such translations."[151] Like Warren Weaver, who had extended Shannon's study of information to the analysis of meaning, Mel'čuk turned Shannon's definition of information into a definition of meaning. Mel'čuk defined it as "an invariant of all synonymous transformations, that is, what is common to all equivalent texts."[152] Furthermore, he explicitly stated that the notion of meaning in the "Meaning—Text" model played the same role that the notion of information played in the cybernetic model of communication. Combining elements of Shannon's "general communication system" and Jakobson's "six constituent factors of verbal communication," Mel'čuk formulated a general cybernetic scheme of verbal communication, and he defined language as "a system of tools for the transfer of information."[153] Mel'čuk then established parallels between three main elements of this general cybernetic scheme and those of the "Meaning—Text" model:

(1) information which is to be received and comprehended; in our model, it is represented by *meanings*;
(2) physical signals which carry this information; in our model, they are represented by *texts*; and
(3) code, that is, the correspondence between information and signals; in our model, it is represented by *the correspondence between meanings and texts*.[154]

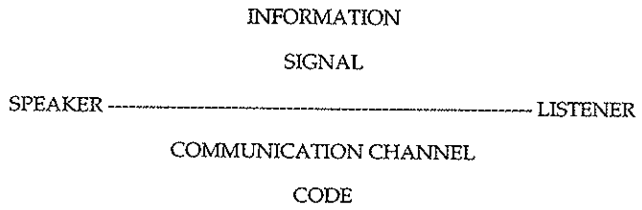

Figure 5.8
The general cybernetic scheme of verbal communication. Adapted from Mel'čuk, *Opyt postroeniia lingvisticheskikh modelei "Smysl—Tekst."*

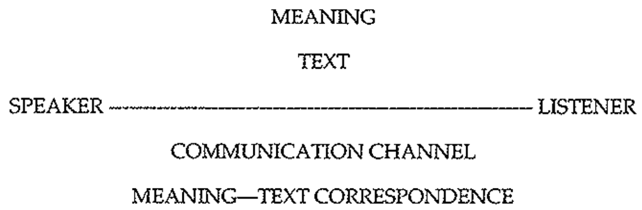

Figure 5.9
The "Meaning—Text" working model of linguistic competence. Adapted from Mel'čuk, *Opyt postroeniia lingvisticheskikh modelei "Smysl—Tekst."*

Linguistics occupied a prominent place both in Liapunov's grand design for the "cybernetization" of Soviet science and in the structure of the Academy Council on Cybernetics. At its inception, the Academy Council included a linguistics section, chaired by Ivanov. Under the umbrella of cybernetic linguistics, this section provided a safe haven for various approaches to the study of language, including descriptive linguistics (usually called "structural linguistics" in the United States), transformational-generative grammar, and Jakobson's phonology. In short, cybernetic linguistics effectively encompassed all the trends in modern linguistics that did not bear the mark of approval by the Soviet linguistics establishment.

Crucial support for the institutionalization of structural linguistics in the Soviet Union came from the Academy Council's chairman, Aksel' Berg. In May of 1960, with Berg's active participation, the presidium of the Soviet Academy of Sciences adopted a resolution "On the Development of Structural and Mathematical Methods in the Study of Language."[155] The resolution called for the organization of structural linguistics sectors in various academic institutions, the launching of the journal *Strukturnaia i matematicheskaia lingvistika* [*Structural and Mathematical Linguistics*], and the founding of the Institute of Semiotics. Soon research groups of structural linguists began to form at various linguistics institutions: the sector of structural and applied linguistics (with a machine translation group) at the Institute of Linguistics, the sector of structural linguistics at the Institute of the Russian Language, the group for the study of language with mathematical methods at the Leningrad branch of the Institute of the Russian Language, the sector of structural typology at the Institute of Slavic Studies (headed by Ivanov), a group at the Institute of Oriental Studies. Moscow University opened a Division of Theoretical and Applied Linguistics within the Philology Faculty (after 1962 the Division of Structural and Applied Linguistics), and soon similar divisions were established at universities in Khar'kov, Kiev, Leningrad, Novosibirsk, Riga, and Tbilisi and at the Institute of Foreign Languages in Moscow.[156]

The strategic alliance between Soviet structural linguistics and cybernetics nearly brought about a merger of the two fields in the early 1960s, when the linguists and the cyberneticians joined forces to lobby for the establishment of a united research institute under the Academy of Sciences. This institute was to provide the material and intellectual resources needed to implement the grand project of the "cybernetization" of Soviet science. The fate of this institute had profound consequences for the future of this project.

The Fate of the Institute of Cybernetics

The establishment of the Academy Council on Cybernetics in April of 1959 only partially solved Soviet cyberneticians' problems: the Council had no funds for research; it only coordinated and disseminated information about cybernetic research done in various academic institutions. Through Liapunov's efforts, the Applied Mathematics Division set up a Department of Cybernetics; by 1960 this department numbered 22 researchers.[157] Liapunov argued that this level of support was utterly insufficient. In November of 1961 he told his colleagues in the division:

> Work in the field of cybernetics in our country is not organized. There is no Institute of Cybernetics in Moscow. . . . Most of the work is done haphazardly and with great shortage of funds. Especially funds for experimental work are lacking. . . . Twenty people for this entire field is a very small number. . . . There is no graduate program in cybernetics. The training of specialists is chaotic. In such conditions, it is very difficult to develop cybernetic research. We need help.[158]

Liapunov argued that the Academy of Sciences should establish a separate Institute of Cybernetics to accommodate all the branches of the cybernetics tree, including computing, "cybernetic biology," mathematical economics, and "cybernetic linguistics." In 1960–61 Liapunov and his colleagues drafted a number of documents outlining the structure of the proposed institute. They argued that the need for such an institute was prompted by the interdisciplinary nature of cybernetics: "Since cybernetics has emerged on the basis of the interaction among different disciplines (mathematics, radioelectronics, logic, biology, linguistics, economics, etc.), it can successfully develop at the present time only in a unified academic body, which would unite representatives of all relevant disciplines."[159]

The Institute of Cybernetics was to unite a large number of cybernetic research groups scattered over various institutions inside and outside the Academy of Sciences: the Department of Cybernetics from the Applied Mathematics Division, the Structural Linguistics Sector from the Institute of the Russian Language, the Structural Linguistics Sector from the Institute of Slavic Studies, the Sector of Structural and Applied Linguistics from the Institute of Linguistics, the machine translation group from the Institute of Precise Mechanics and Computer Technology, a group from the Laboratory of Electrodynamics of the All-Union Institute of Scientific and Technical Information, and several groups from military research institutes.[160] By Soviet standards, the proposed Institute of Cybernetics was of medium size. Liapunov wrote that it "should not be too large; even with all positions filled, there should be no more than 300–350 full-time researchers."[161] Liapunov and his colleague Igor' Poletaev proposed for the institute an unusual administrative structure that would include—besides the conventional "triangle" of a director, an executive director, and an Academic Council—a Council of Project Leaders, which was to play the leading role in directing the affairs of the institute.[162] Liapunov's proposed organizational structure for the institute was as follows:

1. Department of Logic and Cybernetics
a) sector of the theory of control systems;
b) sector of mathematical logic;
c) sector of the theory of programming.
2. Department of Statistics and Cybernetics
a) sector of information theory;
b) sector of the theory of stochastic processes;
c) sector of queuing theory.

3. Department of Semiotics
a) sector of machine translation;
b) sector of mathematical linguistics;
c) sector of informational logical languages;
d) sector of specialized languages of science.
4. Department of Economics and Cybernetics
a) sector of economic control systems;
b) sector of game theory;
c) sector of economic planning.
5. Department of Biology and Cybernetics
a) sector of physiology of the central nervous system and analyzers;
b) sector of biological control systems;
c) sector of self-learning models.
6. Department of Computer Experiments
a) sector of computer operation;
b) sector of computer modeling;
c) sector of computer programming.[163]

The mathematicians Gnedenko, Iablonskii, Khurgin, Markov, and Uspenskii, the linguists Ivanov and Mel'čuk, the geneticist Efroimson, and the computer specialist Kitov were mentioned as candidates for leading research positions at the Institute.

In parallel with cyberneticians' efforts to establish the Institute of Cybernetics, structural linguists lobbied for the creation of an institute of semiotics in Moscow. The linguists proved more successful, and in May of 1960 the presidium of the Soviet Academy of Sciences decided to organize the Institute of Semiotics. The linguists, led by Ivanov, asked the mathematician Andrei Markov Jr. to serve as director, and he agreed. The cyberneticians, led by Liapunov, tried to convince Markov that he should change the name of the institute to "Institute of Semiotics and Cybernetics" and to broaden its research program to include all branches of cybernetics. In June of 1960 leading cyberneticians and structural linguists gathered to discuss this situation. The struggle over the control of the future institute took the form of a lively debate on whether semiotics was part of cybernetics or a separate field. The dispute was resolved by Markov, who announced that semiotics was in fact a part of cybernetics—moreover, its central part—and rejected the name "Institute of Semiotics and Cybernetics" as "not only wrong but also harmful, since it points to the potential possibility of partition."[164] Markov proposed "Institute of Cybernetics," and all sides agreed.

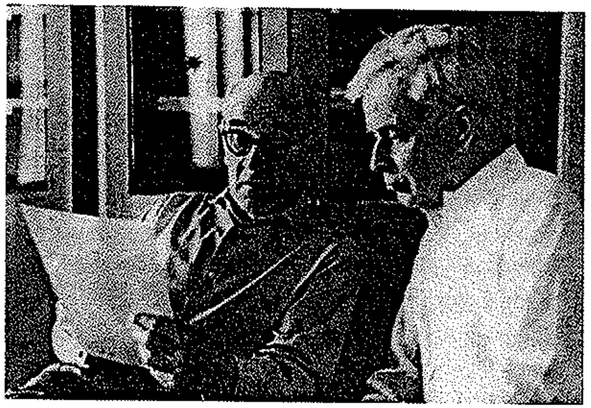

Figure 5.10
Aksel' Berg and Andrei Markov Jr., 1963. From Pospelov and Fet, eds., *Ocherki istorii informatiki v Rossii.*

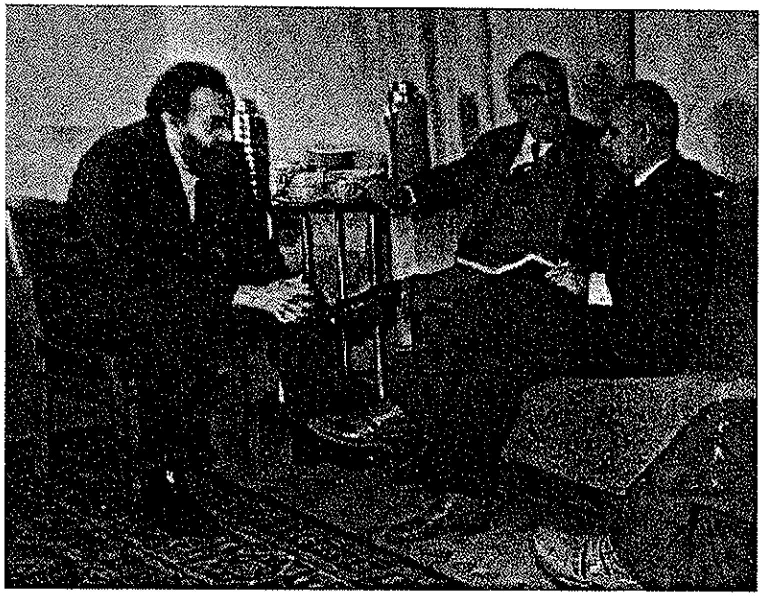

Figure 5.11
At left: Aleksei Liapunov, Norbert Wiener, and Gleb Frank, Moscow, 1960. Courtesy of Natal'ia Liapunova.

The chairman of the Council on Cybernetics, Aksel' Berg, used his connections at the top of the Party and government hierarchy to draw support for the institutionalization of cybernetic research. In July 1961, during a meeting with the newly elected president of the Academy, Mstislav Keldysh, Berg argued that his council was not equipped to develop cybernetic research on a large scale: "We cannot content ourselves with the existence of a merely consultative organ with no rights, no staff, no money, and no office space."[165] He lobbied for the establishment of a whole network of cybernetic research facilities: "We are talking about creating a group of institutes that would study fundamental scientific problems crucially important for medicine, economics, biology, and industry. Comrades from the State Planning Committee and the Central Committee support this idea."[166]

The bureaucratic machine of the Academy moved cautiously and slowly. Finding a building for the new institute posed a formidable problem. Khrushchev's policy of decentralizing scientific research resulted in a ban on the construction of new buildings for academic institutions in Moscow. When discussing possible locations for the institute, Berg even suggested using the sturdy building of the Butyrskaia Prison—which he knew well, having served time there in the late 1930s.[167] Eventually, in September of 1961, the presidium of the Academy of Sciences adopted a resolution to construct a new building for the Institute of Cybernetics in Noginsk, a small town in the Moscow region, in 1963–1965.[168] This was, however, too little too late. Having lost any hope for the organization of the institute in Moscow any time soon, Liapunov moved to the newly built Akademgorodok in Siberia, where excellent living and working conditions were created for him and his staff.[169] Without Liapunov's driving force, the movement for the organization of the institute soon lost its steam. Neither the Institute of Cybernetics nor the Institute of Semiotics materialized.[170] Instead, the Council on Cybernetics acquired the formal status of an academic institute, but without any expansion of its staff.[171]

The failure of the attempts to establish the Institute of Cybernetics reflected deep-seated disagreement and discontent among Soviet cyberneticians. As Uspenskii has later recalled, "various scientific, semi-scientific, academic, and semi-academic groups [had] very different views on how to organize an Institute of Cybernetics."[172] Liapunov and Markov, in particular, strongly disagreed over the research agenda of the future institute.[173]

Multiple interpretations of cybernetics were pulling the Soviet cybernetics community apart. Cybernetics was stretched over too many fields and served too many agendas. The original intention to conceptualize cybernetics as a maximally broad field backfired: reaching a consensus over the meaning of cybernetics became problematic.

"What Is Cybernetics?"

Cyberneticians, who aspired to make other scientific disciplines more objective by "cybernetizing" them, could hardly agree, however, on exactly what *cybernetics* meant. As the cybernetics movement grew wider, the definition of *cybernetics* was becoming broader and broader.

The initial 1955 article by Liapunov, Sobolev, and Kitov described cybernetics as a unity of three theories: information theory, the theory of computers as self-organizing logical processes similar to human thinking, and the theory of automatic control systems (including the study of the nervous system).[174] Three years later, Liapunov and Sobolev published another article, in which they spoke of four definitions, rather than parts, of cybernetics:

1. Cybernetics is a science studying control systems and control processes with mathematical methods.
2. Cybernetics is a science studying the processes of governance and control in machines, living organisms, and human society.
3. Cybernetics is a science studying the processes of transmission, processing, and storing information.
4. Cybernetics is a science studying the methods of creating, transforming, and explicating the structure of algorithms that describe actual control processes.[175]

In 1959 Liapunov and Sobolev published a revised version of this article in which they eliminated the second definition (which, incidentally, was the closest to Norbert Wiener's original conception of cybernetics as a science of "control and communication in the animal and the machine"). Liapunov and Sobolev believed that the notions of *control*, *information*, and *algorithm* were so deeply interconnected that they even could be defined through one another. For example, they defined *information* as "the totality of messages that can be communicated in processes of control." In their view, any "control process" involved some "information processing" governed by certain algorithms. The discursive boundaries between control theory, information theory, and computing vanished altogether when Liapunov and Sobolev defined "the algorithm of information processing in

a given control process" as "the totality of all elementary acts of information processing and all the logical conditions to be checked."[176]

For Liapunov, any intellectual activity was a form of "control process" governed by some "control algorithm," which could in principle be implemented on a computer. Cybernetics, in his view, was to study precisely such (computer) algorithms of control. At the October 1956 session of the Soviet Academy of Sciences, he gave the following definition of cybernetics:

> Any intellectual process, when its algorithm is revealed, no longer requires intellect and can be mechanized. The main condition for the transfer of a certain control process to a machine is the creation of an algorithm that describes this process in terms of elementary logical operations or operations that could be reduced to them and executed by a machine. . . . The science concerned with the methods of construction and analysis of the structure of algorithms . . . and the description of algorithms is a new branch of knowledge known as "cybernetics."[177]

At the same session, Andrei Kolmogorov criticized both Wiener's version of cybernetics (for eclecticism) and Liapunov's version (for reducing cybernetics to computer programming):

> In our country certain comrades, in particular A. A. Liapunov, feel that . . . a theory [that] unites mathematical questions related to the functioning of computers and controlling devices working discretely in time . . . should be called cybernetics. However, the word cybernetics was introduced by N. Wiener, who gave it a much wider significance. Cybernetics according to Wiener . . . includes an important part of the theory of stability for systems of differential equations, classical control theory, the theory of random processes with their extrapolation and filtration, the theory of information, game theory with applications to operations research, the technical aspects of logic algebra, the theory of programming and many other topics. It is easy to understand that as a mathematical discipline cybernetics in Wiener's understanding lacks unity, and it is difficult to imagine productive work in training a specialist, say a postgraduate student, in cybernetics in this sense. If A. A. Liapunov can formulate the program of development of a narrower and more unified discipline, then in my opinion it would be better not to call it cybernetics.[178]

Soon Kolmogorov put forward his own version of cybernetics. In April of 1957, at a session of the Moscow Mathematical Society, he presented a paper titled "What Is Cybernetics?"[179] This paper was a draft of his upcoming article in the *Great Soviet Encyclopedia*, in which he defined cybernetics as a research field studying "the methods of receiving, storing, processing, and using information in machines, living organisms, and their associations." Building on his own work on information theory, Kolmogorov placed the notion of information in the center of his version of cybernetics, and defined other major concepts of cybernetics through this notion. In particular, he defined *communication* as "the receiving, storing, and transmitting of information," and he introduced two varieties of control: *guidance* and *regulation*. Guidance was defined as "the processing of received information into control signals," and regulation as "the processing of received information into regulatory signals."[180] In the same volume of the *Great Soviet Encyclopedia*, Kolmogorov also published an article on information, which he introduced as the main concept of cybernetics.[181]

Even though the appearance of Kolmogorov's article on cybernetics effectively legitimized this field, it did not settle the question of the meaning of the term. Andrei Markov Jr. publicly ridiculed Kolmogorov's definitions, insisting that they produced a vicious circle: cybernetics was defined through information, while information was defined through cybernetics. Kolmogorov responded by redefining information as "an operator that changes the distribution of probabilities in a given set of events." Markov dismissed this definition too, and mockingly described how "a given computer would receive a given operator, which changes the distribution of its probabilities, and store this operator on its magnetic drum."[182] The word *information* was used differently in information theory (where the *amount of information* characterized the diversity of messages produced by the *information source*) and in computing (where the term *information* stood informally for any kind of data processed by a computer). The unification of information theory and computing under the rubric of cybernetics created a new discursive field, in which the two meanings of the term *information* functioned together; this produced the confusion pointed out by Markov.

In 1964, contributing to the ongoing debate, Markov published his own article under the title "What Is Cybernetics?" In it he proposed to define cybernetics as a "general science of causal networks."[183] Markov also redefined information as probabilistic causality: A contains information about B if A causes B with a certain probability. Using his preferred mathematical apparatus, Markov uniformly described such diverse phenomena as the nervous system, a species, a biological population, and an individual organism as probabilistic causal networks.

The mathematician Sergei Iablonskii, a former student of Liapunov's, proposed yet another version of cybernetics. Specializing in algebraic logic, Iablonskii attempted to translate cyberspeak into the language of that

logical theory. In a 1963 article, Liapunov and Iablonskii defined any "control system" as a finite automaton characterized by its state ("memory," or "information"), its structure ("the scheme"), its "coordinates" (self-knowledge, or feedback capacity), and its "function" (its actions, which could change its state, structure, coordinates, or the function itself).[184]

Each of the Soviet mathematicians most actively involved in the cybernetics movement—Kolmogorov, Markov, Liapunov, and Iablonskii—attempted to make his own favorite mathematical theory the foundation of cybernetics. Kolmogorov promoted information theory; Markov advanced causal networks; Iablonskii advocated algebraic logic. Liapunov's mathematical specialty, descriptive set theory, also left a strong imprint on his version of the "cybernetization" of science. In every field, he first delineated elementary concepts and their classes, then defined operations on these classes, then determined the basic theoretical postulates (the "axioms"), and subsequently applied the standard methodology of set theory.[185]

Soviet authors realized that their versions of cybernetics differed significantly from the original Western conceptions of this field. They viewed the works of Western cyberneticians as a point of departure, rather than as a theoretical canon. The physiologist Nikolai Bernshtein frankly admitted that his own vision of cybernetics went far beyond specific Western incarnations of this field:

> We shall treat the term *cybernetics* not as the doctrine of Wiener, Shannon, and Ashby, but rather as a new branch of science, engendered in our times under the pressure of necessity, whose study is associated with the general problems of control theory, information theory, and communications theory.[186]

Liapunov and Iablonskii also acknowledged that their concept of *control system* was much broader than Wiener's notion of *control*; they even admitted that "among control systems may appear certain objects in which there is no control in the usual sense."[187] In Wiener's interpretation, control was always directed at improving organization. For Liapunov and Iablonskii, control was a much looser concept; it included all types of causation, not only those that led to a higher degree of organization. In Liapunov's view, one object exercised control over another if "a signal from the first object [caused] changes in the behavior of the second object."[188] According to Iablonskii, the broad category of control systems included "systems that actually perform control (such as neural tissue or [computer] programs), systems that are controlled (computers, economic systems, and so on), and systems that are not related to control in the usual sense (such as chemical molecules or chess games)."[189] This broad interpretation of control was acceptable, Iablonskii argued, because it was "convenient."

Soviet authors often criticized one another for their free play with cybernetic concepts. Liapunov's heavy emphasis on control upset Kolmogorov, who apparently favored another cybernetic concept: information. In a 1964 private letter, Kolmogorov wrote sarcastically: "Liapunov and others believe that all organic evolution is 'controlled' by someone from above. If the organic life on earth suddenly disappears, this perhaps would be an expression of the highest 'control.'"[190] It was "illegitimate," argued the mathematician Igor' Poletaev, to apply the terms *control* and *information* indiscriminately to describe all interactions between parts of a given system, and to call all systems with such interactions "control systems." He maintained that both Liapunov and Markov described physical systems with terms that related only to their (mathematical) models. "From our perspective," wrote Poletaev, "this 'terminological inaccuracy' is unacceptable, for its leads (and has led already) to a departure from Wiener's original vision of cybernetics toward an inappropriate and irrational expansion of its subject."[191] "As the result," he warned, "the specificity of the cybernetic subject matter completely disappears, and cybernetics turns into an 'all-encompassing science of sciences,' which is against its true nature."[192]

Soviet cyberneticians were concerned about the lack of unity in the cybernetic discourse, but they were not able to reach a consensus. Liapunov and Sobolev, in particular, admitted that the multiple definitions of cybernetics gave the impression of a "great discord dominating in cybernetics." They suggested that readers pay attention not to the "formal definitions" but to the "concrete content" of research, so that cybernetics would be seen as a "sufficiently unified scientific discipline."[193] Aksel' Berg also acknowledged that there was no universally accepted definition of cybernetics, but insisted that scientists could do just fine without it. Definitions were "the concern of philosophers," he wrote. "In mathematics and logic, it would suffice if we are able to operate in practice with such concepts as life, time, space, information, and many others, and also to measure some of them and to express them in quantitative terms."[194]

Cybernetics, which was supposed to bring formal rigor and exact reasoning to the sciences, was itself conspicuously lacking a formal definition. All cyberneticians agreed that it was useful to have a common interdisciplinary language; they strongly differed, however, on the meaning of cybernetic terms. Different members of the cybernetics community had very different intuitive notions about the content and the boundaries of cybernetics. The entire cybernetic project of a deep reformation of science ran into an internal difficulty.