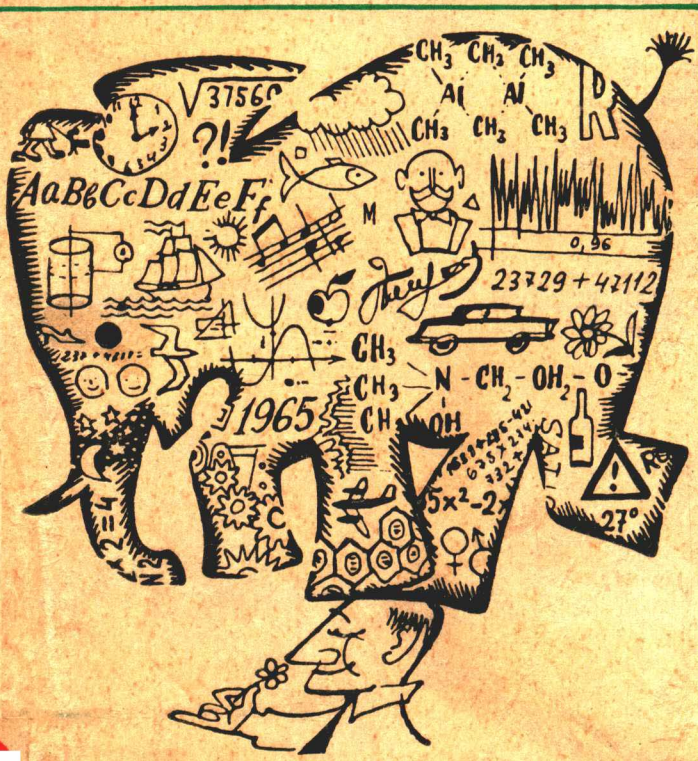
E. Asratyan, P. Simonov



HOW RELIABLE IS THE BRAIN ?

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MIR PUBLISHERS
Moscow

UDC 612.8+612.826.2(0.23)=20

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The fundamental principles underlying the work of the brain, which enable it to function for many years without interruption, today command the interest of experts not only in medicine and biology, but in automation as well. This is because these principles can be utilized to make computing systems more reliable.

Translated from the Russian by
Boris Belitsky

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НАДЕЖНОСТЬ МОЗГА

ИЗДАТЕЛЬСТВО «НАУКА» · МОСКВА

На английском языке

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THE No. 1 PROBLEM

Day and night the mighty turbines of a giant electric station generate power. High-voltage lines transmit the power to consumers: to industrial plants, railways, and communities. The final distributors of the power are substations, and their main installations are power transformers, sometimes the height of a two- or three-storey building.

Unexpected faults may develop in a power system. To assure uninterrupted operation in the event of such an accident, substations have protective relaying systems. Dozens of pick-off elements continuously register apparatus temperature, air and oil pressure, voltage, resistance, power, and current intensity. The signals from these pick-off elements are fed to specially programmed instruments. Any departure from reference inputs at once produces an automatic reaction: part of the consumers are cut off, the reserve is switched in, the transmission is cut out, and audible and light signals make known the breakdown.

The automatic relays are not part of the main power equipment and do not participate in the actual process of power transmission. Yet a

slight fault in a relay or in a measuring circuit can cause a general power failure, despite the fact that the fault in no way affects the fundamental power process. This did, in fact, happen once at a big substation. Late one night its emergency siren started wailing, and factories, mills, and homes were left without power. An examination of the instruments by the staff disclosed that the power failure was due to a faulty relay adjustment.

...The middle of the twentieth century witnessed the birth of the high-speed electronic computer, which opened up truly fantastic vistas in automatic control. The reactions of the new self-regulative devices proved to be swifter and more accurate than those of the unaided human brain. These devices too, however, were found to have their "tendon of Achilles": insufficient reliability. Gerda Evans, a specialist in the computer field, recalls: "Never in my life have I been obliged to sleep and breakfast at such impossible hours as during those months when we sat at our computers for twenty-four hours a day, relieving one another at intervals. The 'ENIAC' on which we worked, though faster than any other previous mathematical apparatus, was temperamental and delicate. Some tube or other or some circuit was for ever going wrong. On those occasions we simply had to wait. Once a storm put the mechanism right off balance. We all sat glued to the telephones in our rooms, waiting for the repair crew to report that we could carry on. Several times they called us up to say that we could come over, as everything would be all right in ten minutes. But when we rushed to the spot, it

would turn out to be another false alarm. So it went on for a whole week."

In the ten years or so since then electronic computers have become larger, more complex, and more advanced. To a certain extent their reliability too has improved, although it still does not satisfy engineers. "In an electronic machine," the Soviet scientist A. A. Lyapunov writes, "a fault in even one of the hundreds of thousands of elements or a break in even one of the hundreds of thousands of contacts can put the whole installation out of order." It will be recalled that at the Brussels World Fair the distribution of hotel accommodations was entrusted to a computer. When the machine developed a fault, 50,000 newly-arrived tourists were left without accommodation for the night. . . .

Reliability is a constantly recurring term in present-day technical literature, the "No. 1 problem", as it has been called by A. I. Berg, Member of the U.S.S.R. Academy of Sciences. From the history of various fields of engineering we know of several "barriers" that arose from time to time to obstruct technical progress: the sound barrier, the heat barrier, the safety factor. The problem of reliability—of the probability that performance indices will be preserved over a specified period—is of paramount importance for the pervasive development of automation.

At the same time this important and formidable problem of modern automation and remote control has been solved brilliantly by nature in the brain, which at the human level is proving capable of creating more and more complicated automatic devices. The thousands of millions of

nerve cells—those tiny live "relays"—function for scores of years. Round the clock the internal organs continue their work: the heart beats, the blood circulates, and the lungs are ventilated. Except for the hours of sleep, the brain, in addition to regulating the functions of the internal organs, is also directing the "external" activities of the organism: the acquisition of individual experience, adaptation to environment, and—in man's case—the refashioning of the environment to suit his needs. Environmental conditions change continuously: darkness is followed by bright sunlight; frost, by scorching heat. Periods of relative tranquillity are followed by emergencies in which the organism strains all its resources. But the brain functions without interruption.

The organism and its "control panel", the central nervous system, are exposed to dozens of harmful, destructive influences. Mechanical, thermal, biological, and radiation effects injure eyes and limbs (receptor and effector organs) and damage nerve channels. Not infrequently the central nervous system itself is impaired: injuries, haemorrhages, and infectious processes destroy certain sections of the brain. But even in these emergency situations the brain continues to assure the vital functions of the organism and, after a certain period of time, the impaired functions are completely or partially restored.

Even the most imaginative mind cannot fail to be amazed by the compensatory capabilities of the central nervous system and, especially, its higher parts. A woman by the name of Olga Skorokhodova, blind and deaf since early childhood, has become an eminent educator. The writer Ni-

kolai Ostrovsky, confined to his bed by mortal illness, created remarkable works of literature. A pilot with both feet amputated, Alexei Maresyev, returned to his fighter plane and shot down many more Nazi planes.

Yet next door, in the world of man's mechanical helpmates, a failure in a single part of secondary importance reduces to naught the work of extremely complicated installations.

It is this striking contrast that suggests considering the specific ways and means by which nature has solved "the No. 1 problem". Quite obviously, the mechanisms that make living regulating systems reliable cannot be borrowed directly by modern engineering. The qualitative distinctions of living matter—and, foremost among them, the continuous self-renewal of its chemical composition—have placed their mark on all the manifestations of vital activity, including the laws that govern the functioning of the nerve cells. That is why our interest must be not so much in the specific elements of the structure and activities of the central nervous system as in the fundamental principles of biological protection from harmful influences, in the principles of the dynamic readjustment of damaged systems, and in the basic laws governing the compensation of impaired functions.

The problem of restoring impaired functions of the central nervous system—the supreme regulator of the living organism's activities—has for many years commanded the attention of our laboratory, now part of the Institute of Higher Nervous Activity and Neurophysiology of the Academy of Sciences of the U.S.S.R. In our ex-

position of the subject we shall, naturally, draw primarily upon the results of our own research over a period of thirty years. A popular survey of everything accomplished in the field of brain function compensation is not our object, although we shall, of course, refer to the work of many other investigators and research groups.

It is difficult to say, at the start of this survey, what exactly will prove useful to the designer, the innovator, and the engineer. Compensation phenomena will be described as they appear to the physiologist. It is for the reader to determine what can be utilized in kindred areas of science.

The writers have deliberately rejected any interpretation of biological phenomena in mathematical and engineering terms; nor will they make extensive use of terms borrowed from cybernetics or draw tempting parallels. This has been rejected for two reasons. The first is that all too often lately there have been attempts to fill in the gaps in definite knowledge about the functioning of the brain with cybernetic phraseology, which leads the reader to confuse hypothetic conjectures with what is really known to science about the central nervous system. The second reason is that as important as mathematics is to biological research and as important as it is to subject biological phenomena to mathematical analysis, mathematics is by no means the only form of theoretical thinking for the physiologist. Our science has a system of theoretical concepts of its own that can so far be translated into mathematical terms only partly.

In the belief that little will be accomplished by superficial digressions into cybernetics, the writers have confined themselves strictly to the field in which they are working, neurophysiology; it is their hope that the popular form of exposition will make their essays useful to workers in other fields of learning.