Gelfand on mathematics and neurophysiology

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It is well known that Gelfand's scientific interests were not limited to mathematics. One of non-mathematical field where Israel Moiseevich Gelfand worked was neurophysiology. In late 1950s, he organized neurophysiological seminar and few years later he spearheaded two neurophysiological research groups: one at the Institute of Biophysics (after 1967, this group moved to the Institute for the Problems of Information Transmission), and another at Moscow University. As a member of one of these groups, I was lucky to work with Gelfand for about 30 years.

I think that the late 1950s and early 1960s were the most romantic years for neurophysiology. It was a time when the scientific world was strongly impressed by the works of Wiener, Shannon, Von Neumann, Turing, McCulloch, Pitts and others. At that time many mathematicians, physicists, and engineers were drawn to neurophysiology. The common idea was that new mathematic approaches (such as the theory of information, game theory, automata theory, mathematical logic, etc.), as well as the modeling of neural functions, including the creation of artificial intelligence, could lead neurophysiology to understand the mechanisms of brain functions, including the mechanism of mind. This enthusiasm was strongly supported by achievements in microelectrode techniques that allowed recording the activities of single brain cells – neurons. These studies showed that neurons interact with each other by electrical impulses of constant amplitude. Therefore, neurons were regarded as digital elements having two discrete states – 0 and 1, while the whole brain was seen as complex computational machinery. This idea of the brain as computational machinery remains the dominant view to this day.

As to I.M. Gelfand, the deeper he plunged into neurophysiology, the more disappointed he became by the idea of using direct mathematical approaches for solving neurophysiological tasks. He used to say that modern mathematics developed in close contact with physics and engineering, whereas neurophysiological processes are much more complex than the physical. Although analytical and computer models may be useful in solving certain specific tasks, this kind of modeling is usually no more than an attempt to bring down the highest complexity of non-formalized neurophysiological processes to the complexity of physical processes that can be formalized and described with existing mathematical language. I.M. Gelfand articulated most of his ideas concerning the so-called "mathematical approach" to living systems in his Kyoto Prize Lecture. There, he emphasized that this kind of approach is rather dangerous, because it usually implies the priority of mathematical and computer models over real biological systems. In many cases, models are considered as full substitutes for natural phenomena, and become subjects of self-perpetuating studies. Paradoxically, the better is a model, the more dangerous it may become, because it could push researchers to use the initial postulates underlying the model far beyond their applicability. In that lecture, I.M. Gelfand noted that the relationship between real biological systems and mathematical models is similar to the relationship between psychology and behaviorism, which reduces the complex psychological world to outward behavior.

Unlike physical hypotheses that are formulated as mathematical models, fruitful neurobiological hypotheses can be formulated, at least at present, as fairly general ideas, and the value of these ideas is determined by the number of non-trivial experimental works they inspire (see preface to the book “The Cerebellum and Rhythmical Movements” by Y.I. Arshavsky, I.M. Gelfand, G.N. Orlovsky written by I.M.). I will mention two general ideas introduced by I.M. Gelfand and his student Mikhail L’vovich Tsetlin – ideas that proved to be rather fruitful in initiating experimental studies. These ideas are related to the problem of motor control – the main field covered in the laboratories founded by I.M. Gelfand, although their general applicability can be broader. The first is “the hypothesis on the non-individualized mode of control in complex systems”. One of the main objectives of the motor control system is to overcome a redundant number of degrees of freedom of the peripheral motor apparatus and to diminish the number of independent variables underpinning different movements. Following the famous Russian neuroscientist Nicolai Aleksandrovich Bernstein, I.M. Gelfand and M.L. Tsetlin suggested that, in evolution, this problem was to a great extent solved by a hierarchical, multi-level organization of the motor control system. A complex control system includes a number of relatively autonomic subsystems – synergies, each of them performing its own task. Higher levels of the system do not control each single element of lower levels, but send “general” commands to subsystems. Expedient behavior of subsystems is determined not by a descending command, but by their internal organization, formed in the course of embryonic development and/or learning. The direct result of this hypothesis was the discovery by Grigori Orlovsky, Fiodor Severin, and Mark Shik of the locomotor command area in the brain stem. They showed that a simple electrical stimulation of this area evokes well-coordinated locomotor movements – walking or running, depending on the strength of stimulation – in the preparation of the cat with removed hemispheres. This “preparation with controlled locomotion” was widely used in studies of neural mechanisms of locomotor control by scientists from different countries. The second idea was formulated as “the principle of minimal interaction.” The motor control system includes a dozen of neural centers located at different levels of the nervous system. The problem is how these centers “agree” with each other in short intervals of time. I.M. Gelfand and M.L. Tsetlin postulated that, at each moment, the motor control system seeks to bring the body to a position at which all possible interactions within the system are minimal. Presently, Anatol Feldman and Mark Latash successfully use this idea in analyses of mechanisms for controlling posture and arbitrary movements in a man.

The widely accepted concept, presently known as the connectionist concept, that the brain is a form of computational machinery consisting of simple digital elements was particularly alien to I.M. Gelfand. Everybody in this audience knows that, according to I.M. Gelfand, the main problem of science is the problem of “adequate language.” For a formulation of adequate logic there must be language that does not simplify a real situation. His viewpoint was that the situation in which neuroscientists use the language of electrical spikes and synaptic connections as the only language in their interaction with the nervous system, should unavoidably lead to principal roadblocks in understanding the higher, cognitive functions of the brain. Computational models of cognitive functions, even those looking flawlessly logical and convincing, are usually incorrect, because they use non-adequate language. I.M. Gelfand believed that the language of cognitive neuroscience should be shifted away from the commonly-accepted “network” language to the intracellularly-oriented direction. My guess is that this was among reasons for I.M. Gelfand to shift his biological interests from neurophysiology to cell biology. He used to ask us –a group of young electrophysiologists, whether we really believed that neurons do not have, metaphorically speaking, a “soul,” but only electrical potentials. In other words, Gelfand’s idea was that the highest levels of the brain include complex, “smart” neurons, performing their own functions and that the whole cognitive function is the result of cooperative work of these complex neurons. As far as I know, most of Gelfand’s colleagues have been admired by his fantastic intuition in mathematics. I think that Gelfand’s idea that neurons can have not only electrical potentials, but also a “soul” shows that his intuition extended far beyond mathematics.