V. L. Dunin-Barkovskiĭ. *Multineuronal structures: theory and experiment.* In 1984–1986 tens of articles on the theory of information processes in neuronal structures were published in physics journals.[1,2] Their appearance is a result of both the intrinsic theoretical progress achieved in the neurosciences[3,4] and the "social order": electronic circuits have now achieved the level of the brain with respect to the number of elementary operations per 1 s per 1 cm^3, but are not as efficient as the brain in the solution of many problems of information processing. The main achievement of the theory prior to Hopfield[6] was the discovery of the nontrivial possibilities of multineuronal structures: memory circuits consisting of 10^3–10^5 neuron-like elements with a random linkage law, which exhibit practically determinate behavior (error probability of 10^{-5}–10^{-7}) and high stability to damage with low redundancy, have been found.[3,4]

The theory of deep structures in the brain (cerebellum, cortex of the large hemispheres, etc.), unlike the theory of sensorial systems (vision, hearing), deals with the lowest level of representation and processing of information, i.e., the representation of numbers and operations on them. The digital limit for representing numbers by the activity of a network of N neurons corresponds to 2^N of the significant states of the network, and the analog limit corresponds to N states. If the number M of significant states of the network is such that

$$N \ll M \ll 2^N, \qquad (1)$$

then it is in principle possible to organize a computational process so as to provide a large (compared with N) range of representation of numbers and noise immunity of the calculations. Significant states of the network can form in configuration space of the neuron network a connected topological manifold (more precisely, its finite model, the proximity of the states of the network—according to the number of neurons with different states). It is possible to achieve a state such that the structure of such a manifold would correspond to the structure of the manifold of admissible values of the variables of the object being modeled.[6] The mathematical operations correspond to mappings of pairs of one-dimensional manifolds into one-dimensional manifolds into one-dimensional manifolds. Examples of nontrivial families of one-dimensional manifolds in the configuration space of a neuronal network can be obtained in models of the recording and reproduction (with different neuron thresholds) of sequences of excitations of neurons (Fig. 1).[7]

An example of a successful interaction of theory and experiment in neurophysiology is the analysis of memory in the cerebellum[3,8–11]—the most regular division of the nerve system. A theory of the operation of the cerebellum was proposed in 1969.[3] The theory is based on the hypothesis that the combined excitation of granule cells and climbing fibers, operating on one Purkinje cell, determines which granule cells operate effectively on the Purkinje cell. This hypothesis has been confirmed experimentally in Refs. 9 and 10 and in other works. In particular, under different conditions the efficiency of the synapses of the granule cells on Purkinje cells can both decrease[9] and increase[10] after simultaneous activation of the climbing fiber and of the granule cell. The data presented in Fig. 2 illustrate the increase in the probability of the responses of the Purkinje cell to stimulation of the granule cells after the combination of the excitation of the granule cells and of the climbing fiber.[10]

The development of a theory of learning in the cerebellum and the calculation of its consequences led to the discovery of the critical quantityof information stored in a Purkinje

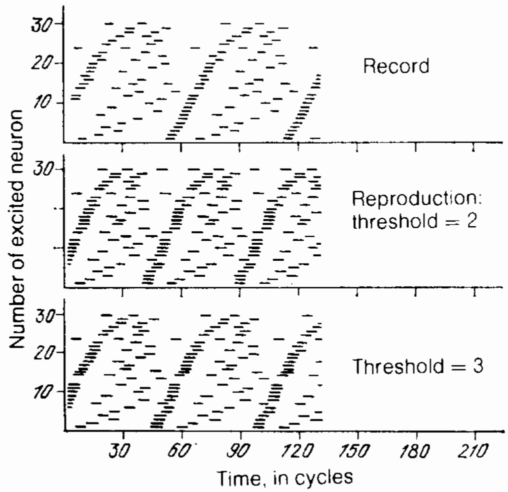

FIG. 1.

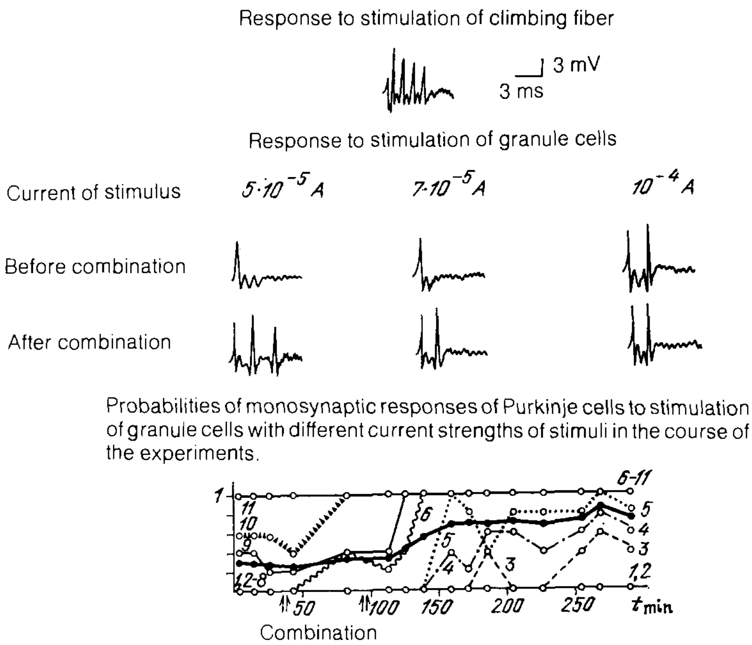

FIG. 2.

cell.[8] If the number of situations stored is less than the critical value, the conditional probability that the input situation has been learned by the Purkinje cell, under the condition that the cell reacted to it in the same manner as to a learned situation, is close to one, and when the critical value is exceeded this probability is close to zero.[8] Analytical and simulation calculations enable finding the optimal ratio between the suppressing and stimulating effects on the Purkinje cell, allowing the maximum number of well-learned situations.[1] The value of the optimal ratio of the coupling parameters changes by a factor of N (N is the number of synapses in the Purkinje cell; $N = 10^5$ for the human cerebellum) depending on whether or not the weight of the synapse of the granule cell increases or decreases with learning.[11] Experiments on further checking of the consequences of the theory of learning in the cerebellum have been proposed.[8,9,11]

Models of noise-resistant associative memory,[5] which have attracted the attention of many theoretical physicists,[1,2] are rediscoveries of neural network effects discovered by D. Marr (1945–1980) in the theory of the archicortex and neocortex.[3] The development of the theory of these effects (Refs. 1, 2, 4–8, 11 and others) is necessary for further progress in the understanding of neuronal mechanisms. Effort must be concentrated on the construction of theories which have verifiable consequences, and it must be realized in the neurosciences that experiments must be performed on checking the modern theories which have been developed.

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