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A NEW APPROACH TO THE DEVELOPMENT OF ARTIFICIAL INTELLIGENCE SIMILAR TO HUMAN INTELLIGENCE

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Annotation. The article discusses a new approach to the creation of artificial neurons and neural networks as a means of developing artificial intelligence similar to natural. Based on the consideration and analysis of the works of physiologists on the structure and functions of a biological neuron, it was found that the information perceived by a person is stored in the neurons of the brain at the molecular level, it also suggested that the nucleus and endoplasmic reticulum are elements of processing, transformation and storage of temporary and long temporary memory. In addition, it was suggested that the nerve cell of the brain is molecular, using signals or information represented by a continuously variable physical quantity, a supercomputer, that performs the analysis, synthesis, processing and storage of information. Huge amounts of information perceived by a person from the moment of his birth and throughout his life are stored in the endoplasmic reticulum of the neuron. There are about 100 billion neurons in the human brain, and each neuron contains millions of membrane-bound ribosomes that biosynthesize and modify protein molecules that are transferred to the secretory vesicles. When one synaptic vesicle is emptied, a portion of the mediator is ejected into the synaptic cleft, including about 10,000 molecules. If we assume that one molecule corresponds to one unit of information, then human memory is unlimited. A detailed consideration of the fundamentals of the functioning of a biological neuron from the standpoint of a cybernetic system approach led to the understanding that it is necessary to develop an artificial neuron of a new type. This made it possible to develop the most approximate analog of a biological neuron - a neural-like element and a neural-like growing network. A description of the neural-like element is given. The process of perception and memorization of information in a neural-like element with the simultaneous formation of a neural-like growing network and their application in models of intelligent systems is shown.

Keywords: biological neuron, neural-like element, neural-like growing network, learning, memorization.

Introduction

Artificial intelligence (AI) was developed by scientists in the 1950s to teach machines to solve problems that only humans could handle. Since then, research in the field of artificial intelligence has come a long way. Many scientific papers have been written. A huge number of AI programs have been developed. Various types of robots have been created. So, for example, most recently at the Tesla AI Day 2022 presentation, Elon Musk presented the first working sample of the Tesla Optimus humanoid robot. The robot can carry boxes, wave hands and water plants. Thanks to computer vision based on autopilot, the Optimus robot freely navigates in space. Elon Musk said that the current humanoid robots of competing brands are "brainless", and Optimus should become "the ultimate capable robot" because it will be controlled by an artificial intelligence system that Tesla is now honing on the example of electric vehicle automatic control system. According to Elon Musk, in the future, the robot will be able to perform tasks that will replace a person in certain areas of activity. So, he will be able to cook dinners, mow the lawn and take care of the elderly. Versions of Optimus will even be able to become "buddies" for people. But so far there is not a single development with AI that fully corresponds to human intelligence. AI is divided into three types. A limited AI capable of solving only one specific task, such as playing chess. General AI is partially comparable to human and multitasking. Super intelligent AI - must surpass the human brain in all respects. Very popular and promising today, machine learning (ML) is a type of AI. The essence of ML is that computers learn on their own from a huge amount of data. Some experts believe that AI is not humanoid robots or computers. This is a global network that unites all the information capabilities of the planet and they fear that at any moment AI can get out of control and humanity will not be able to cope with it. Indeed, failures in the global network are already comparable in scale to disasters, but this network is still very far from super-intelligent AI. To create a super intelligent AI, it is necessary to develop a system that has functionality similar to the functionality of human intelligence. What is human intelligence? In various dictionaries, intelligence is defined as follows: ***Intelligence*** - (*Latin intellectus - mind, reason*) mind, ability to think, insight, the totality of those mental functions (comparisons, abstractions, concept formations, judgments, conclusions, etc.) that turn perceptions into knowledge or critically review and analyze already existing knowledge. Back in the Middle Ages, a controversial issue arose: is the will subordinate to the intellect or, conversely, the intellect is the will. The first point of view was represented by Thomas Aquinas, the second by such English thinkers as Dune Scotus and William of Ockham. Now the prevailing view is that although the intellect, like the will, depends on the relevant circumstances, yet, as belonging to the sphere of the spirit, it is higher than the will, which belongs to the mental sphere. *Philosophical encyclopedic dictionary. 2010.*

Intelligence (*lat. intellectus - mind, reason, mind*) in the general sense, the ability to think; in epistemology - the ability to mediate, abstract knowledge, which includes such functions as comparison, abstraction, concept formation, judgment, inference; opposes direct types of knowledge - sensual and intuitive; in psychology - rational thinking, subject to the laws of logic; opposes irrational spheres of the psyche - emotions, imagination, will, etc. *New Philosophical Encyclopedia: In 4 vols. M.: Thought. Edited by V. S. Stepin. 2001.*

Intelligence*, -a, m. Mind* (in 1 meaning), thinking ability, mental beginning in a person. High and. II adj. Intellectual. Intellectual ability. Intellectual property (the legally protected product of someone's intellectual labor). *Explanatory dictionary of Ozhegov*.

Meaning of the word intellect in the English dictionary. The first definition of intellect in the dictionary is the capacity for understanding, thinking, and reasoning, as distinct from feeling or wishing. Other definition of intellect is a mind or intelligence, esp a brilliant one. Intellect is also a person possessing a brilliant mind; brain.

From the foregoing, it is clear that the intellect is a mental principle in a person, the ability for indirect, abstract cognition, which includes the following functions: the ability to think, insight, the totality of those mental functions (comparisons, abstractions, concept formation, judgments, conclusions, subject to laws logic, thinking, etc.), which turn perceptions into knowledge or critically review and analyze existing knowledge.

Such intelligence has not yet been created.

One of the first attempts to describe the principles by which a "thinking" machine, similar to the brain, could work was the work of W. McColloch and W. Pitts "The logical calculus of ideas related to nervous activity." The mathematical model of the biological neuron they proposed was a very innovative invention. In modern neural networks used in AI development, the McCallock-Pitts artificial neuron is mainly used. However, it is a very simplified model of a real biological neuron. The mathematical model of a biological neuron, proposed by W. McCollock and W. Pitts, focuses on a purely mathematical function of a biological neuron and does not take into account many features of the functioning of real biological neurons, for example, analysis and synthesis of perceived information.

To develop artificial intelligence similar to human intelligence, it is necessary to develop an artificial neuron as the main element of a new type of neural networks, in terms of their functions as close as possible to a biological neuron. To this end, consider the structure and functions of a biological neuron.

Neuron

The neuron consists of the actual body of the neuron and processes - dendrites and an axon (Fig.1).

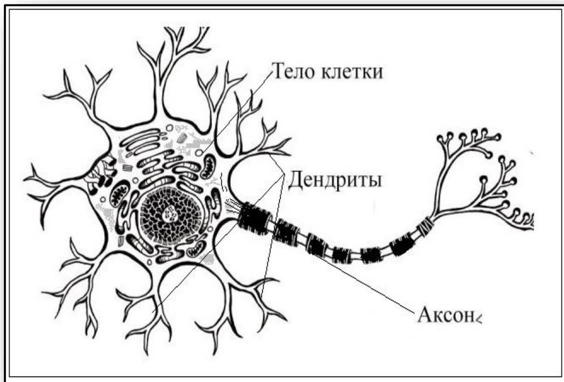

Fig. 1. Neuron

The bodies of neurons make up the gray matter of the brain. Dendrites are branched processes of a neuron that receive impulses from other neurons. An axon is a long process of a nerve cell. These cells are able to establish contacts with other cells, receive, process, encode, transmit and store information [1].

Structure of a neuron

For different cells of the body, including neurons, some common structural components are characteristic of the constant components of the cell - organelles, which are located in its inner part - the cytoplasm. Figure 2. shows the structure of a neuron cell and its constituent organelles.

1.Axodendric synapse - a synapse in which the axon contacts the dendritic process of the neuron.

2.Axosomatic synapse - a synapse in which the axon of one neuron contacts the cell body (soma) of another.

3.Presynaptic vesicle - the vacuole containing the neurotransmitter is located in the presynaptic membrane.

4.Presynaptic membrane - part of the surface membrane of the nerve fiber through which the mediator is released.

5.Synaptic cleft - the space between the presynaptic membrane and the postsynaptic membrane, which contains the connecting pre- and postsynapse structures.

6.Post-synaptic membrane - a thickened surface membrane of the cell in the area of the synapse, which is sensitive to the mediator.

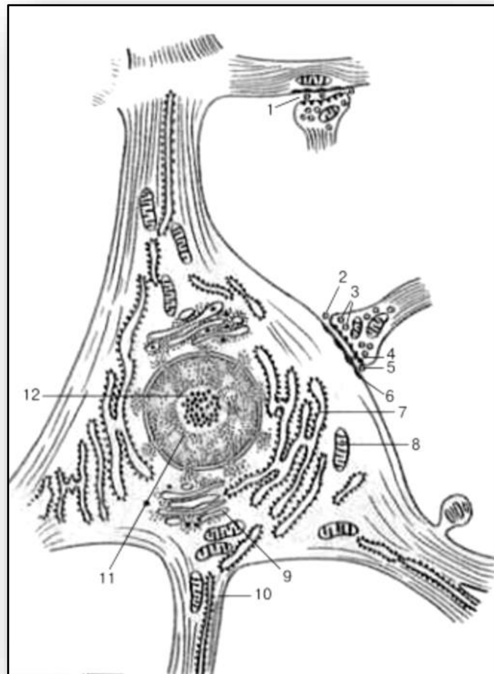

Fig. 2. Cell structure of a neuron

7.Endoplasmic reticulum (ER) (endoplasmic reticulum (ER)). The endoplasmic reticulum is the intracellular factory for the production of proteins. It consists of many membranes on which ribosomes accumulate.

8.Mitochondria are two-membrane organelles that contain deoxyribonucleic (DNA) and ribonucleic (RNA) acids.

9.The Golgi apparatus (AG) is a complex network of cavities that are the site of protein modification.

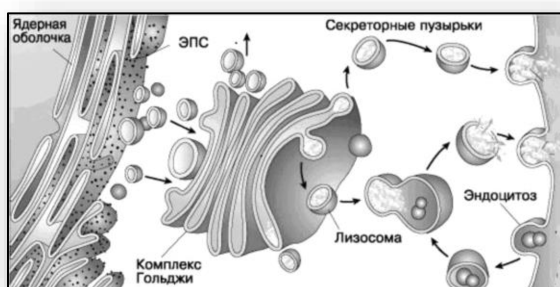

Fig. 3. The Golgi apparatus

AG is designed to remove proteins synthesized in the endoplasmic reticulum. Modified proteins are transported by vesicles to cell compartments, lysosomes, cytoplasmic membrane, or secretory vesicles. Secretory vesicles release their contents into the extracellular space (exocytosis).

10.Neurofibrils - filamentous structures of the cytoplasm of a neuron, forming a dense network in the cell body and parallel bundles in the processes. Participate in the conduction of nerve impulses.

11.Cell nucleus - controls cellular processes and is the controlling center of the cell. Contains DNA molecules - genetic information. The nucleus stores, transmits and implements hereditary information, and also provides protein synthesis.

12.Nucleolus. In the nucleus of nerve cells there is one, and sometimes 2-3 nucleoli. An increase in the number of nucleoli is accompanied by an increase in the activity of neurons. The main function of the nucleolus is the synthesis of ribosomal RNA and ribosomes [2 - 4].

Gene expression is the realization of the information embedded in them, that is, the synthesis of RNA and proteins. Gene expression includes two successive steps: transcription and translation. In cells, transcription occurs in the

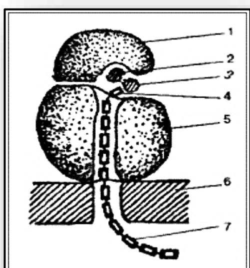

Fig. 4. The structure of the ribosome

nucleus, where messenger RNA (mRNA) is synthesized from the DNA template. Translation occurs in the cytoplasm of the cell in ribosomes, where the polypeptide is synthesized from the mRNA template [5].

The ribosome is the most important organelle of a living cell (Fig. 4). Ribosomes are present in all cell types. They are formed in the nucleus, then leave it and are located in: the cytoplasm; mitochondria; plastids; on the membranes of the endoplasmic reticulum (ER). The ribosome consists of: small subunit - 1; messenger RNA (or messenger RNA) - 2; tRNA (transfer RNA) - 3; amino acids - 4; large subunit - 5; membranes of the endoplasmic reticulum - 6; polypeptide chain - 7.

Ribosomes synthesize protein from amino acids based on the genetic information provided by messenger RNA (mRNA). Scheme of protein synthesis in the ribosome (Fig. 5). After the mRNA leaves the nucleus into the cytoplasm, a ribosome joins it, thereby initiating the assembly of the protein-synthesizing system. Then the process of translation begins - the synthesis of a protein molecule from amino acids, which are delivered to the ribosome by transfer RNA (tRNA). Different tRNAs carry different anticodons corresponding to mRNA codons. A codon is three nucleotides that code for a particular amino acid. The amino acid corresponding to its "own" codon is attached to the other end of the tRNA.

On the ribosome, tRNAs line up against

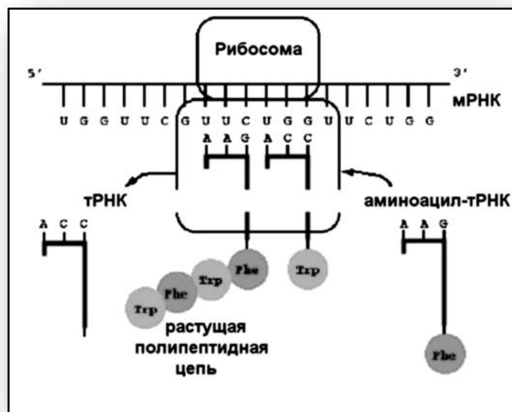

Fig. 5. Scheme of protein synthesis in the ribosome

mRNAs. The codon and anticodon must match, otherwise the tRNA is detached. After the addition of each new amino acid, the ribosome subunits move along the mRNA chain by one codon [6].

Scientists have found that the composition of the ribosome can change in cells and these changes depend on the state of the external environment. In a nerve cell, they depend on external information. With the help of the most modern technologies, it has been established that mammalian cells contain ribosomes of different composition! It turned out that in the same cell there is not one heterogeneous population of ribosomes, but several such populations at once! They do not replace each other, but coexist simultaneously. It has been experimentally proven that each of the populations predominantly translates only a certain set of mRNAs. This means that ribosomes are not universal, that is, they are not capable of translating absolutely any mRNA molecule, as previously thought. Separate groups of ribosomes interact only with some mRNAs and, therefore, are “responsible” for the synthesis of only a part of cellular proteins [5]. Proteins are not only the primary cellular building material, but there are also a number of proteins that perform a regulatory function in intracellular processes, transmit signals between tissues, internal organs and at the cellular level, help move, etc.

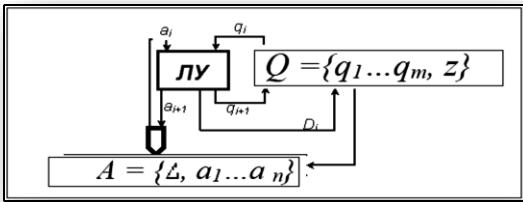

Fig. 6. The structure of the Turing machine

The number of ribosomes in a cell is quite large - more than 15 thousand per cell. One ribosome synthesizes protein at a rate of 15–20 amino acids per second. At the same time, she makes mistakes quite rarely - one mistake happens in 3000 amino acids. Thus, the work of the ribosome is a highly precise process. The famous American biochemist Bruce Alberts even compared the ribosome with a “molecular machine”, thus emphasizing the coherence and elegance of this complex molecular complex.

It should be noted that to some extent he was right. The structure and functions of ribosomes almost completely coincide with the structure and functions of the Turing machine. A Turing machine consists of three parts: a tape, a read-write head, and a logic device (Fig. 6). The tape acts as external memory and is considered unlimited.

The machine operates in an arbitrary finite alphabet $A = \{\Delta, a_1 \dots a_n\}$- this alphabet is called external. The processing of information and the issuance of commands for writing a sign, as well as shifting the tape in the Turing machine, is carried out by a logical unit (LU). The LU can be in one of the states that form a finite set and are denoted by $Q= \{q_1 \dots q_m,\ z\}$, (similar to mRNA in the sense of an analog with ribosomal protein synthesis), moreover, the state z (analog 3') corresponds to the completion of work, and q_1 (analog 5') is the initial (original).
$A = \{\Delta,\ a_1 \dots a_n\}$ is the external alphabet of the machine (similar to tRNA ribosomes).

The functioning of the Turing machine: at step i, a sign from the currently monitored cell (a_i,) is sent to one input of the LU, and a sign indicating the state of the LU at the moment (q_i) is sent to the other input (On the ribosome, tRNAs line up against mRNA. Codon and the anticodon must match). Depending on the received combination of signs (a_i, q_i) and the available processing rules, the LU generates and sends a new sign (a_{i+1}) to the monitored cell via the first output channel, issues a command to move the head (D_{i+1} from R, L and S), and also gives a command to call the next control character (q_i+1). (Similarly, after the addition of each new amino acid, the subunits of the ribosome move along the mRNA chain by one codon.) A specific Turing machine is specified by enumerating the elements of the sets A and Q, as well as by the logical function that the LU implements, i.e. set of transformation rules.

Consider the solution of the problem of adding 1 to the number n in decimal notation, for example, 219+1; through a Turing machine. We use the external alphabet $A=\{0,1,\dots,9,\Delta\}$, in which the symbol Δ corresponds to an empty sign.

The internal alphabet is formed by two states – working (q) and stopping (z) $(Q = \{q, z\})$. The initial number n, as well as the result - $n + 1$ - are written in the decimal system, and the numbers are placed one at a time in adjacent cells without gaps. The functional diagram is represented by a table. The row corresponds to the state q, and the columns correspond to the characters of the external alphabet:

a	0	1	2	3	4	5	6	7	8	9	Δ
q	z1S	z2S	z3S	z4S	z5S	z6S	z7S	z8S	z9S	q0L	z1S

Let the initial configuration be *21q9*.

Step 1. *q9→q0L*, i.e. 9 will be replaced by *0* and the head will move to the tens place - intermediate configuration *2q10*.

Step 2. *q1→z2S*, i.e. *1* will be replaced by *2* and a stop will occur with a final configuration of *2z20*, i.e. the result of addition is *219+1=220*.

The described algorithm provides the summation of any integer decimal number and one. In order to perform addition with some integer m, this algorithm must be repeated m times. Multiplication of integers can also be reduced to adding a number to itself. Therefore, Turing machines have an important property - the ability to build a new machine by combining existing ones. Those. different algorithms are implemented by different Turing machines. (Similarly, in the same cell there is not one population of ribosomes, but several at once. They coexist simultaneously and implement different algorithms).

The Turing machine is extremely simple in design. It has an elementary simple set of operations. Access to memory cells (tape sections) in it occurs not by address, but by sequential movement along the tape. For this reason, actions such as adding or comparing two characters are performed by the Turing machine in several steps, and the usual operations of addition and multiplication require a very large number of elementary operations.

The Turing machine was invented in order to show the theoretical possibility of constructing an arbitrarily complex algorithm from extremely simple operations [6].

Axon

An axon is a long process of a nerve cell. The protoplasm of the axon contains neurofibrils, mitochondria and microtubules. Microtubules form the cell cytoskeleton and are used for particle transport (axon transport) [7].

The axon transmits impulses to other nerve cells through synapses.

Synapse

The synapse consists of a presynaptic membrane, a postsynaptic membrane, and a synaptic cleft (Fig. 8).

Signals pass through the synapse in the

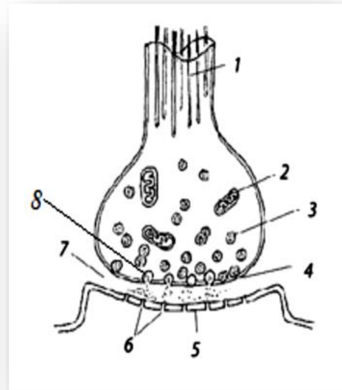

Fig. 7. Synapse structure:
1 microtubule; 2 mitochondria; 3 synaptic vesicles; 4 presynaptic membrane; 5 postsynaptic membrane; 6 receptors; 7 synaptic cleft; 8 mediator exocytosis.

form of chemicals and electrical signals. Each neuron can have thousands of synapses.

The presynaptic membrane is the end of the process of the nerve cell. Inside the process, there is an accumulation of vesicles containing the neurotransmitter. The postsynaptic membrane is the thickened part of the cell membrane. It contains receptors that perceive the action of mediators. A feature of receptors is the ability to enter into biochemical interaction only with a certain type of mediator. It has now been found that a single mediator can bind to several different receptors and induce different responses.

The synaptic cleft is a fluid-filled space between the pre- and postsynaptic membranes through which the mediator diffuses from the presynaptic membrane to the postsynaptic one. Functionally, synapses are divided into excitatory, in which an excitatory postsynaptic potential is generated, and inhibitory, which causes the appearance of an inhibitory postsynaptic potential [8].

According to the method of transmission of excitation, synapses are divided into: chemical and electrical.

In an electrical synapse, excitation is transmitted by analogy with the propagation of excitation in a nerve fiber. An electrical current that occurs between the presynaptic and postsynaptic membranes irritates the postsynaptic membrane and causes the generation of an action potential in it. The transmission of excitation in a chemical synapse is a complex physiological process. This process proceeds in several stages: mediator synthesis, mediator secretion, mediator interaction with the postsynaptic membrane, mediator inactivation. In the cytoplasm of neurons, chemical mediators are synthesized - biologically active substances. In nerve cell communication, the basic units of information are transmitted by synaptic mediators, with a particular neuron using the same mediator in all of its synapses.

“People communicating with each other convey the content of their thoughts in words. To express emotions or emphasize the additional meaning of words, they use the power of their voices, facial expressions, and gestures. This analogy with verbal and non-verbal communication shows that some chemical mediators convey "facts", while others convey additional semantic shades. Currently, it is not known exactly how many neurotransmitters exist. Scientists have already found more than a hundred of these chemical transmitters responsible for various functions of the human body. For example, the neurotransmitter acetylcholine is responsible for memory, muscle contraction, and the ability to absorb information. Dopamine is associated with pleasant feelings and thinking. Endorphins are responsible for the sensation of pain and emotion” [9, 10]. The release of the mediator from synaptic vesicles has a quantum character. The contents of the synaptic vesicles are released into the synaptic cleft by exocytosis.

Transfer of information in neurons

Exocytosis is a process that involves the movement of substances from the cell into the external environment. During exocytosis, membrane-bound synaptic vesicles containing cellular molecules are transferred to the plasma membrane. Vesicles fuse with the cell membrane and expel their contents outside the cell. When one synaptic vesicle is emptied, a portion (quantum) of the mediator is ejected into the synaptic cleft, mediator includes about 10,000 molecules. The interaction of the mediator with its receptors causes excitation, which is a response of the neuron to irritation and is characterized by an increase in the functions of the neuron or inhibition, characterized by a decrease in the functions of the neuron. Primary inhibition in the CNS occurs due to inhibitory neurons. There are two types of primary inhibition: postsynaptic and presynaptic. Postsynaptic inhibition occurs when the axon of the inhibitory neuron synapses with the body of the neuron and inhibits cell activity. Presynaptic inhibition occurs when the axon of inhibitory neuron synapses with the axon of an excitatory neuron, preventing impulse conduction. The interaction of the processes of excitation and inhibition underlies the coordination activity of the CNS [3].

Exocytosis is the opposite of endocytosis, in which substances move into the interior of the cell. Endocytosis, depending on the mechanism, is usually divided into two broad categories - phagocytosis (capture of very large particles) and pinocytosis (capture of liquids, as well as molecules dissolved in them). Endocytosis plays a key role in the development of the body, the immune response, fat metabolism, the maintenance of cell size, and the transmission of signals into the cell [3].

Endocytosis is of particular interest, since the transfer of information between neurons, which occurs in synapses, is directly associated with the intensive use of this mechanism. The process of information transfer between neurons of "communication of neurons" is described in the article "Endocytosis in the nervous system" published by Corresponding Member of the Russian Academy of Medical Sciences A. L. Zefirov and Candidate of Biological Sciences A. M. Petrov [11].

In Fig. 8 A, B, C shows the process of information transfer between a neuron and a secretory or muscle cell. A - a long process of a neuron (axon) is in contact with a short process (dendrite) of another neuron. The resulting action potential causes the secretion of a neurotransmitter, which quickly reaches the receptors on the postsynaptic membrane. A population (4) and subsequent preparation for exocytosis (5).

The precursors of synaptic vesicles are formed in the nerve cell (a); their maturation is associated with several rounds of endocytosis

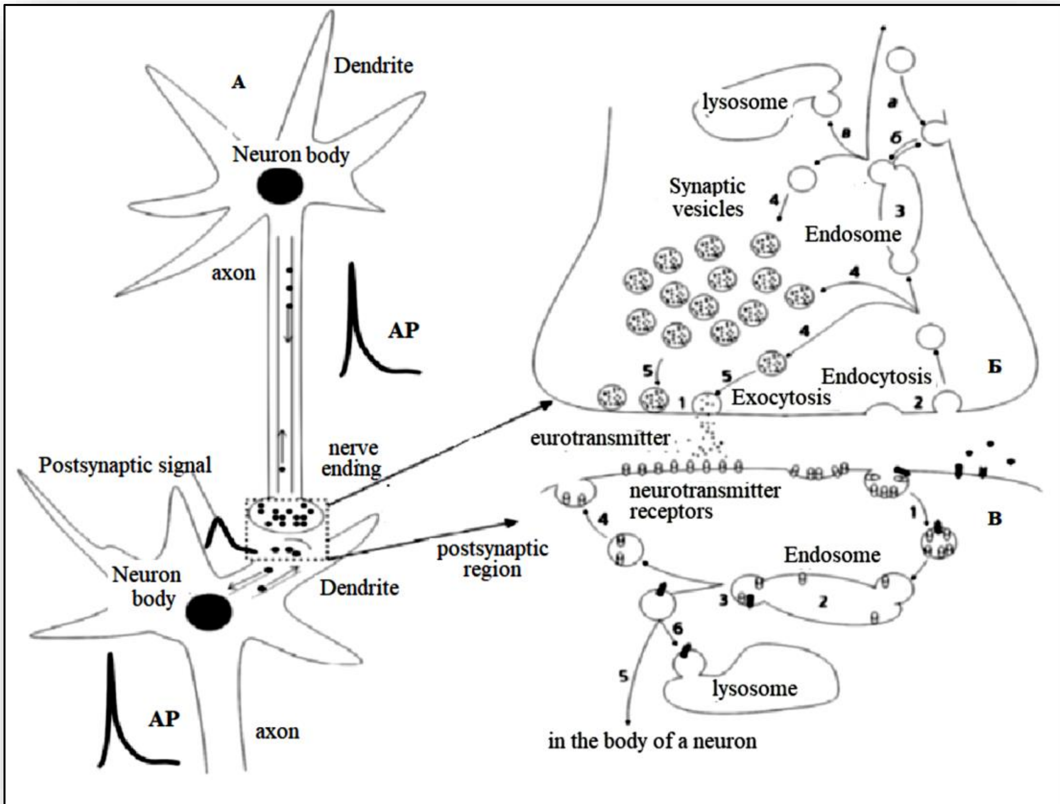

Fig. 8. Vesicular cycles in the synapse. "(Endocytosis in the nervous system" A. Zefirov, A. Petrov)

postsynaptic signal arises, with a sufficient value of which an action potential propagates in the second neuron. “In response to a nerve impulse, vesicles fuse with the presynaptic membrane (exocytosis), releasing a neurotransmitter into the synaptic cleft. Having reached the receptors on the postsynaptic membrane, the neurotransmitter activates them, resulting in an electrical signal. Its value determines the excitation in the postsynaptic cell.

The more neurotransmitter released by the vesicles, the stronger the postsynaptic response and the more reliable the transmission of excitation” [11].

B - presynaptic vesicular cycle includes: exocytosis (1), endocytosis (2), sorting of membrane material in the endosome (3), transport of vesicles with inclusion in their (b), after which they are sent to lysosomes for degradation (c).

C, postsynaptic vesicular cycle. Some postsynaptic membrane receptors are taken up during endocytosis (1) and targeted to endosomes (2). Part of the receptors, if necessary, can return to the cell surface: with the help of a clathrin-dependent mechanism, the vesicle carrying them (3) buds, which merges (4) with the postsynaptic membrane.

Other receptors are delivered into the cell (5) or poisoned into lysosomes (6).

Such changes in postsynaptic receptors are important for many integral processes of the nervous system (learning, memory, motor control, etc.). Postsynaptic endocytosis can regulate the synthesis of proteins, including receptors. For example, activated nerve growth factor receptors are taken up, sorted in endosomes, and then transported in endocytic vesicles to the neuron body. There, receptors, due to their enzymatic activity, act on factors that control the reading of information from certain genes and the subsequent synthesis of proteins (including receptors for neurotransmitters). Vesicles deliver the newly formed receptors back to the postsynaptic membrane and are embedded in it, while it becomes more receptive to the neurotransmitter. Thus, the analysis, synthesis, transformation and memorization of information is carried out in the nerve cell.

In addition, considering that when one synaptic vesicle is emptied, a portion (quantum) of the mediator, which includes about 10,000 molecules, is ejected into the synaptic cleft, it can be assumed that simultaneously with the appearance of an electrical signal, information packet, represented by a set of molecules that is formed in the ER. “The endoplasmic reticulum is an intracellular factory for the production of proteins, it consists of many densely packed membranes on which ribosomes accumulate, which directly carry out protein synthesis.

In addition, it was found that protein biosynthesis is activated upon excitation of neurons at different levels of CNS organization, and blockade of protein synthesis makes it difficult or eliminates the formation of long-term memory.

Memorization of information

Memorization of information in a nerve cell occurs as follows. The acid released from the end of the neuron acts on the receptors located on the surface of the postsynaptic neuron and triggers the production of the second messenger. The secondary messenger, through a cascade of regulatory reactions, enhances the synthesis of proteins integrated into the neuron membrane for the best capture of signals from the most active presynaptic ending, which transmits information about the characteristics of the memory object. The incorporation of new receptors into the membrane increases the efficiency of synaptic transmission, and the sum of excitatory postsynaptic potentials from incoming signals reaches a threshold level, an action potential arises, and a response is triggered - action on the result of recognition. In the future, the memory neuron continues to maintain the concentration of receptors on the postsynaptic membrane of the synapse at the same high level. It is this property of neurons that ensures the extraordinary stability of memorization, which makes it possible to consider it as a specific variant of long-term memory (Fig. 9).

Thus, the memorization of information is carried out in the nerve cell and is associated with the synthesis of proteins, which is carried out in ribosomes from amino acids based on the genetic information provided by messenger RNA.

In each neuron, millions of ribosomes are fixed on the ER membrane! There are about 100 billion neurons in the human brain. Perhaps it is in the endoplasmic reticulum that huge amounts of information perceived by a person are stored. If so, then human memory is limitless. The brain from the moment of birth of a person stores everything to the smallest detail throughout his life.

Memory

Our knowledge, actions, experiences, impressions do not disappear without a trace, but are stored in our memory. Human memory is encoded in billions of nerve cells and trillions of connections between them. Memory demonstrates the amazing properties of the human mind. Memory remembers everything. Memory is the ability of the nervous system to retain information about the events of the external world and the body's reactions to these events for a long time. Learning and memory are sides of the same process. Learning primarily refers to the mechanisms for acquiring information, and memory refers to the mechanisms for storing and retrieving this information. A person remembers not only the stimuli that affect him, but also the sensations and emotions that these stimuli cause. It is only thanks to memory that animals and man can acquire, preserve and use individual experience. and emotions that these stimuli cause.

Learning and memorization are determined by the genetic programs of the cognitive activity of many highly developed living beings. Thanks to them, knowledge and assessment of the state of the environment takes place, without which adaptation to it and survival is impossible.

Understanding the fundamentals of the functioning of a nerve cell from the standpoint of a cybernetic system approach made it possible to develop a neural-like element (NE) as a model closest to a biological neuron.

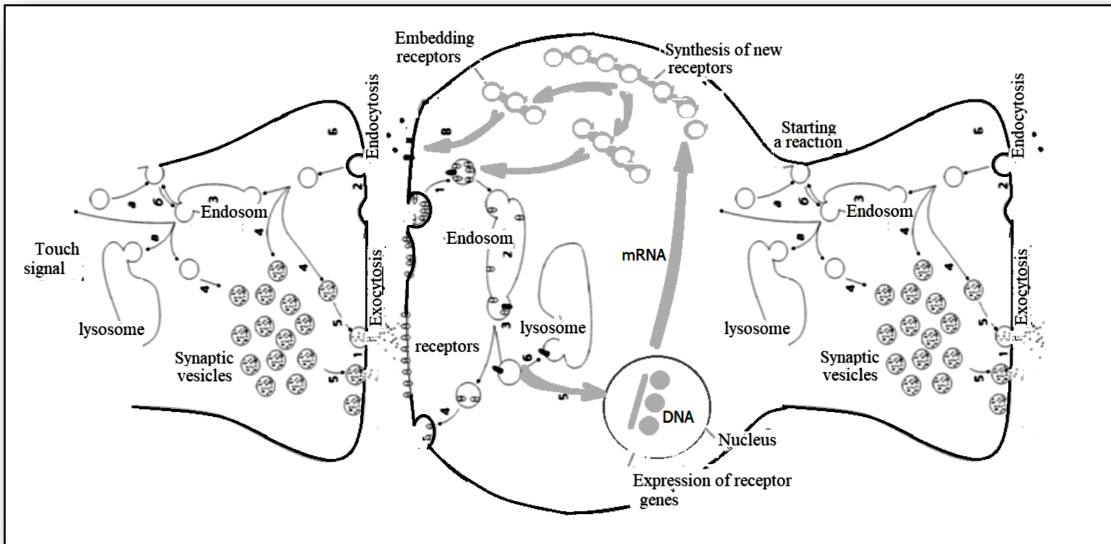

Fig. 9. Scheme of storing information in a neuron

Neural element

A neural-like element (Patent UA 128798 G06G 7/60 (2006.01)) consists of a device (analogous to the cell body) with many excitatory, inhibitory $\vec{a}, \vec{a}'$ and modulating $\vec{b}$ inputs and one output Q. The output (analogous to an axon) consists of a plurality of conductors and a plurality of endings. Information (codes, bursts) is received at the inputs of the device. The device processes information and in accordance with mutually exclusive relations *R1*, *R2*, *R3*, *R4*, *R5*. On the set of pairs of vectors $\vec{a}, \vec{a}' \in A$, five main mutually exclusive relations *R1*, *R2*, *R3*, *R4*, *R5* are defined.

$$\vec{a}\ R1_r \vec{a}' \equiv \forall \vec{a}_i^j, \vec{a}_i^{j+1} \in A: (\vec{a}_i^j \times \vec{a}_i^{j+1} = \vec{a}_i^j) \cap (\vec{a}_i^j \times \vec{a}_i^{j+1} = \vec{a}_i^{j+1}) \cap (\vec{a}_i^j \times \vec{a}_i^{j+1} \neq 0),$$

here $\vec{a}_i^j \times \vec{a}_i^{j+1}$- conjunction of vectors $\vec{a}_i^j$ and $\vec{a}_i^{j+1}$, ∩ - logical AND;

$$\vec{a}\ R2_r \vec{a}' \neq \forall \vec{a}_i^j, \vec{a}_i^{j+1} \in A: (\vec{a}_i^j \times \vec{a}_i^{j+1} \neq \vec{a}_i^j) \cap (\vec{a}_i^j \times \vec{a}_i^{j+1} \neq \vec{a}_i^{j+1}) \cap (\vec{a}_i^j \times \vec{a}_i^{j+1} = 0);$$

$$\vec{a}\ R3_r \vec{a}' \equiv \forall \vec{a}_i^j, \vec{a}_i^{j+1} \in A: (\vec{a}_i^j \times \vec{a}_i^{j+1} \neq \vec{a}_i^j) \cap (\vec{a}_i^j \times \vec{a}_i^{j+1} \neq \vec{a}_i^{j+1}) \cup (\vec{a}_i^j \times \vec{a}_i^{j+1} \neq 0);$$

$$\vec{a}\ R_r 4 \vec{a}' \equiv \forall \vec{a}_i^j, \vec{a}_i^{j+1} \in A: (\vec{a}_i^j \times \vec{a}_i^{j+1} \neq \vec{a}_i^j) \cap (\vec{a}_i^j \times \vec{a}_i^{j+1} = \vec{a}_i^{j+1}) \cup (\vec{a}_i^j \times \vec{a}_i^{j+1} \neq 0);$$

$$\vec{a}\ R_r 5 \vec{a}^{©} \equiv \forall \vec{a}_i^j, \vec{a}_i^{j+1} \in A: (\vec{a}_i^j \times \vec{a}_i^{j+1} = \vec{a}_i^j) \cap (\vec{a}_i^j \times \vec{a}_i^{j+1} \neq \vec{a}_i^{j+1}) \cap (\vec{a}_i^j \times \vec{a}_i^{j+1} \neq 0).$$

Based on these relations, the operations of analysis and synthesis of information are respectively performed:

$$Q_{r1}^1(\vec{a}, \vec{a}') = (\vec{a}_{ri}^1, \vec{a}_{ri}^k, \vec{a}_{ri}^{k+1}), \vec{a}_{ri}^1 := \vec{a}_{ri}^1, \vec{a}_{ri}^k := 0,\ \vec{a}_{ri}^{k+1} := 0, m_k^{\vec{a}_i^1} := b_k,$$
$$m_k^{\vec{a}_i^2} := b_k, P_{\vec{a}_i^1}^0 = f(m_k^{\vec{a}_i^1}), P_{\vec{a}_i^2}^0 = f(m_k^{\vec{a}_i^2});$$

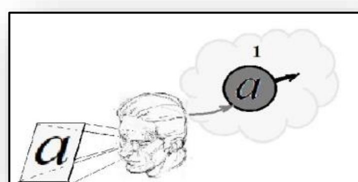

Fig. 10. Letter «*a*» memorization

$$Q^{2}_{r1}(\vec{a},\vec{a}') = (\vec{a}^{1}_{ri},\vec{a}^{k}_{ri},\vec{a}^{k+1}_{ri}), \vec{a}^{1}_{ri} := \vec{a}^{1}_{ri}, \vec{a}^{k}_{ri} := \vec{a}^{k}_{ri},\ \vec{a}^{k+1}_{ri} := 0, m^{\vec{a}^{1}_{i}}_{k} := b_k,$$
$$m^{\vec{a}^{2}_{i}}_{k} := b_k, P^{0}_{\vec{a}^{1}_{i}} = f(m^{\vec{a}^{1}_{i}}_{k}), P^{0}_{\vec{a}^{2}_{i}} = f(m^{\vec{a}^{2}_{i}}_{k});$$

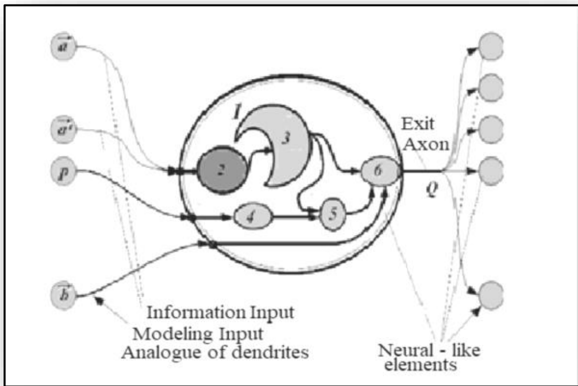

Fig. 11. Neural-like element

$$Q^{3}_{r1}(\vec{a},\vec{a}') = (\vec{a}^{1}_{ri},\vec{a}^{k}_{ri},\vec{a}^{k+1}_{ri}), \vec{a}^{1}_{ri} := (\overline{\vec{a}^{1}_{ri}\times\vec{a}^{k}_{ri}}\times\vec{a}^{1}_{ri})\cup c_{rj}, \vec{a}^{k}_{ri} := (\overline{\vec{a}^{1}_{ri}\times\vec{a}^{k}_{ri}}\times$$
$$\times\vec{a}^{k}_{ri})\cup c_{rj}, \vec{a}^{k+1}_{ri} := \vec{a}^{1}_{ri}\times\vec{a}^{k}_{ri}, m^{\vec{a}^{1}_{i}}_{k} := b_k, m^{\vec{a}^{k}_{i}}_{k} := b_k, m^{\vec{a}^{1,k}_{i}}_{c} := f(P^{0}_{\vec{a}^{k+1}_{i}}),$$
$$P^{0}_{\vec{a}^{k+1}_{i}} = f(m^{\vec{a}^{+1k}_{i}}_{k}), P^{0}_{\vec{a}^{1}_{i}} = f(m^{\vec{a}^{1}_{i}}_{k}, m^{\vec{a}^{1}_{i}}_{c}), P^{0}_{\vec{a}^{k}_{i}} = f(m^{\vec{a}^{k}_{i}}_{k}, m^{\vec{a}^{k}_{i}}_{c});$$

$$Q^{4}_{r1}(\vec{a},\vec{a}') = (\vec{a}^{1}_{ri},\vec{a}^{k}_{ri},\vec{a}^{k+1}_{ri}), \vec{a}^{1}_{ri} := (\overline{\vec{a}^{1}_{ri}\times\vec{a}^{k}_{ri}}\times\vec{a}^{1}_{ri})\cup c_{rj}, \vec{a}^{k}_{ri} := \vec{a}^{k}_{ri},$$
$$\vec{a}^{k+1}_{ri} := 0, m^{\vec{a}^{1}_{i}}_{k} := b_k, m^{\vec{a}^{k}_{i}}_{k} := b_k, m^{\vec{a}^{k}_{i}}_{c} := f(P^{0}_{\vec{a}^{k}_{i}}), P^{0}_{\vec{a}^{k}_{i}} = f(m^{\vec{a}^{k}_{i}}_{k}),$$
$$P^{0}_{\vec{a}^{1}_{i}} = f(m^{\vec{a}^{1}_{i}}_{k}, m^{\vec{a}^{1}_{i}}_{c});$$

$$Q^{5}_{r1}(\vec{a},\vec{a}') = (\vec{a}^{1}_{ri},\vec{a}^{k}_{ri},\vec{a}^{k+1}_{ri}), \vec{a}^{1}_{ri} := \vec{a}^{1}_{ri}, \vec{a}^{k}_{ri} := (\overline{\vec{a}^{1}_{ri}\times\vec{a}^{k}_{ri}}\times\vec{a}^{k}_{ri})\cup c_{rj}, \vec{a}^{k+1}_{ri} := 0,$$
$$m^{\vec{a}^{1}_{i}}_{k} := b_k, m^{\vec{a}^{k}_{i}}_{k} := b_k, m^{\vec{a}^{k}_{i}}_{c} := f(P^{0}_{\vec{a}^{1}_{i}}), P^{0}_{\vec{a}^{1}_{i}} = f(m^{\vec{a}^{1}_{i}}_{k}), P^{0}_{\vec{a}^{k}_{i}} = f(m^{\vec{a}^{k}_{i}}_{k}, m^{\vec{a}^{k}_{i}}_{c}).$$

Here $\cup$ is the disjunction of vectors applied to the components of the vectors.

if $\vec{a}^{1}_{ri} \neq \vec{a}^{k}_{ri}$,

then $\vec{a}^{1}_{ri} := \vec{a}^{1}_{ri},\ \vec{a}^{k}_{ri} := \vec{a}^{k}_{ri},\ \vec{a}^{k+1}_{ri} := 0,$

$m^{a^1_i}_{k} := b^{r^1_i}_{k},\quad m^{a^1_i}_{k} := b^{r^1_i}_{k},$

$P^{0}_{a^1_i} = f(m^{a^1_i}_{k}),\ \ P^{0}_{a^1_i} = f(m^{a^1_i}_{k})$, if $\vec{a}^{1}_{ri} = \vec{a}^{k}_{ri}$,

then $\vec{a}^{k}_{ri} := 0,\ \vec{a}^{k+1}_{ri} := 0,\ m^{a^1_i}_{k} := b_k,$

$P^{0}_{a^1_i} = f(m^{a^1_i}_{k})$.

$$k = \begin{cases} 1, \text{ if operation } Qrj^{1}, \\ 2, \text{ if operation } Q_{r1}^{2}, Q_{r1}^{4}, Q_{r1}^{5}, \\ 3, \text{ if operation } Qrj^{3}. \end{cases}$$

Here P_i is the excitation threshold of the neural-like element a_{ir}. $P_i = f(m_i)$ provided that

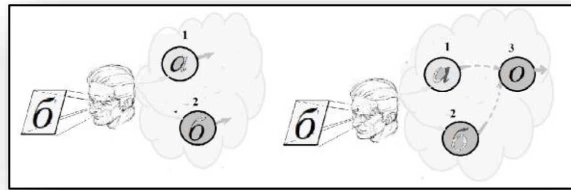

Fig. 12. Letter «*б*» memorization

the set of connections D_r, coming to the neural-like element air corresponds to the set of values (weight coefficients) $M_r = \{m_i\}$, $i = \overline{1, w}$, and m_i can take both positive and negative values.

The block diagram of the neural-like element is shown in Fig. 11. NE contains the following blocks: 1 - neural-like element; 2 - block for determining the relations *R1, R2, R3, R4, R5* on the set of pairs of vectors; 3 - block for determining operations Q_{rj}^{1}, Q_{rj}^{2}, Q_{rj}^{3}, Q_{rj}^{4} or $Q_{rj}^{5}$and generating control codes; 4 - block for storing the minimum allowable threshold for excitation of a neural-like element; 5 - block comparing the threshold of excitation with the minimum allowable threshold of excitation of the neural-like element; 6 - block allowing the passage of the output code; $\vec{a}, \vec{a}'$ – information inputs; $\vec{b}$ – modulating input; *Q* - information output [12].

Block 2 (analogous to the nucleus of a biological neuron) - contains information incorporated during the development of an intellectual system (genetic information), stores, transmits and implements hereditary information (for example, when performing unconditioned reflexes), and also provides the synthesis of new information. Block 3 (an approximate analog of the rough endoplasmic reticulum).

In a neural-like element, analysis, distinguishing differences, classification, synthesis, generalization and memorization of perceived information are carried out, as well as codes are developed for forming connections between neural-like elements, i.e. formation of a growing neural network. In accordance with the values of the features that characterize the input information, the level of excitation of the neural-like element is determined. A neural-like element, being a model of a biological neuron, works in accordance with its functioning.

Memorizing visual information in a neural-like element

Let's consider the work of a neural-like element using the example of memorizing and recognizing letters of the Russian alphabet. The information describing the image of the letter "*a*", in the form of a Boolean vector $\vec{a}$, enters the receptors of the neural-like element 1. The information is processed in accordance with mutually exclusive relations *R1*, *R2*, *R3*, *R4*, *R5* and stored (Fig.10). NE1 is transferred to an excited state.

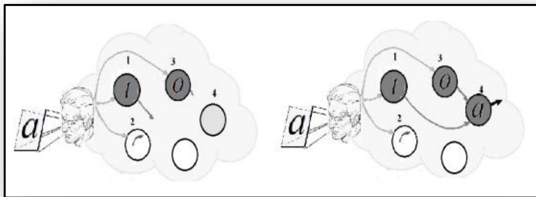

Fig. 13. Letter «*a*» memorization

If the image of the letter "*b*", in the form of a Boolean vector, enters the NE1,2 receptors. A is performed. In NE1,2 coincident receptors are excited and transferred to NE3. As a result, the information describing the letters "*a*"and "*b*" is divided and stored in NE 1-3 (Fig. 12). Analysis completed. The information was divided into signs characterizing the letters "*a*" and "*b*".

Now, if the image of the letter "*a*", in the form of a boolean vector $\vec{a}$, enters the NE1-3 receptors. Pairs of vectors in NE1-3 are processed in accordance with mutually exclusive relations *R1, R2, R3, R4, R5.* Based on these relations, the following operations Q_{rj}^{1}, Q_{rj}^{2}, Q_{rj}^{3}, Q_{rj}^{4}, Q_{rj}^{5} of analysis and synthesis of information

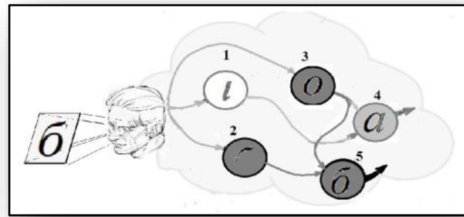

Fig. 14. Letter «*б*» memorization

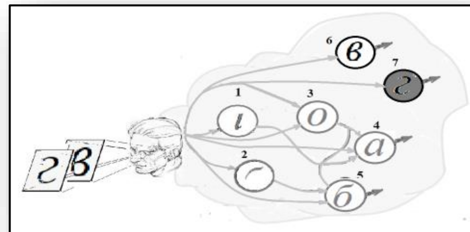

Fig. 15. Letter «*в* and *г*» memorization

pair of vectors is processed according to mutually exclusive relations *R1, R2, R3, R4, R5.* Based on these relations, the following operations Q_{rj}^{1}, Q_{rj}^{2}, Q_{rj}^{3}, Q_{rj}^{4}, Q_{rj}^{5} of analysis and synthesis of information in the NE are determined. A pair of vectors $(\vec{a},\vec{б})$ in NE1,2 is in relation to *R3*, respectively, the operation Q_{rj}^{3} in the NE are determined. A pair of vectors in NE1 is in relation to *R5*, operation Qrj5 is performed. A pair of vectors in NE2 is in relation to *R2*, the operation Q_{rj}^{2} is performed. A pair of vectors in NE3 is in relation to R5, operation Q_{rj}^{5} is performed. In NE1,3 there is a complete coincidence of parts of the signs of the letter "*a*". NE1,3 are excited to the maximum, connect with the nearest spontaneously excited NE4 and transmit information. As a result, the letter "*a*" is synthesized and remembered in NE5 (Fig. 13).

The information describing the image of the letter "*b*", in the form of a boolean vector, enters the NE1-4 receptors (Fig. 14).

Pairs of vectors are processed according to

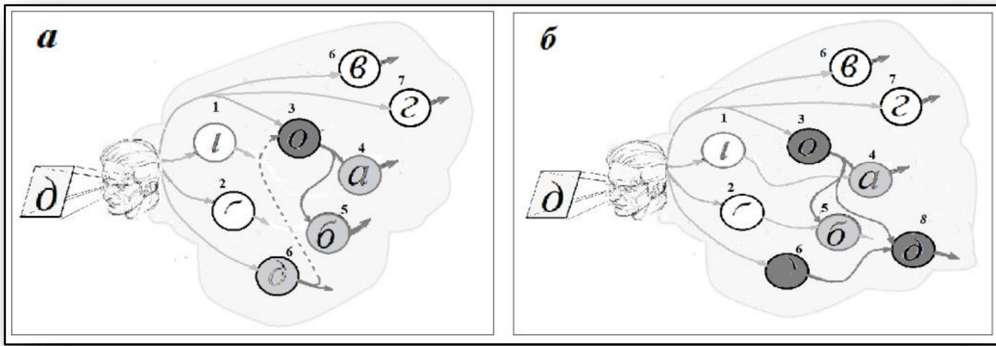

Fig. 16. Letter «*д*» memorization

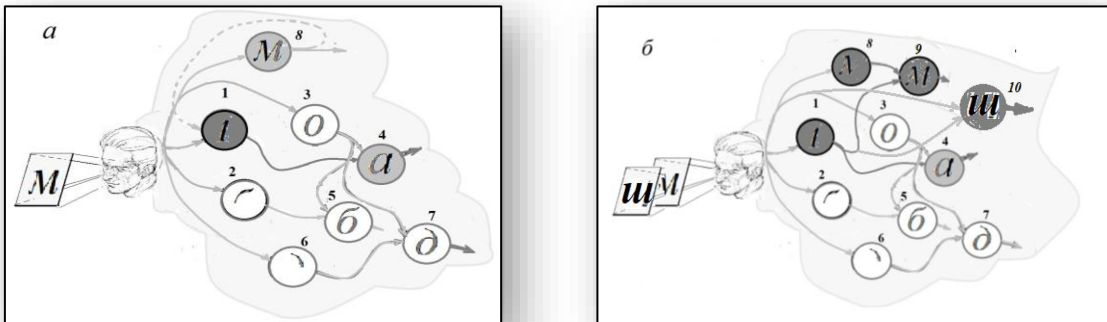

Fig. 17. Letter «*м*» memorization

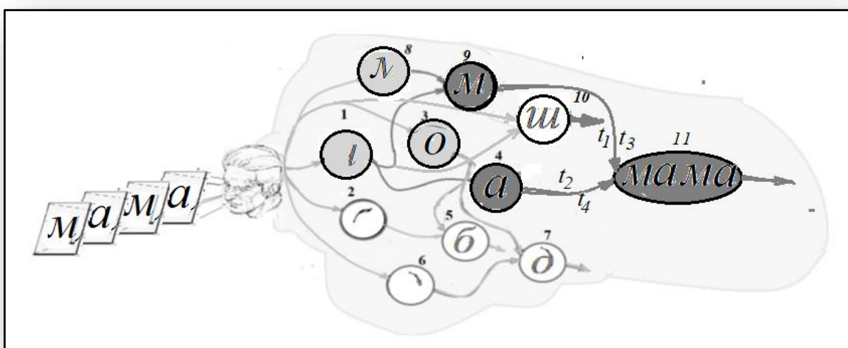

Fig. 18. Letter «*мама*» memorization

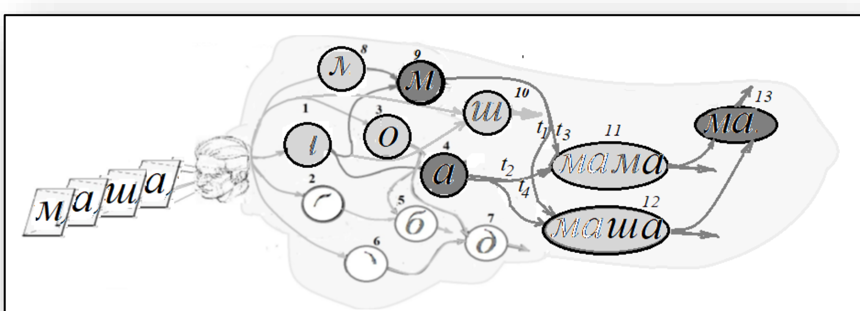

Fig. 19. Letter «*маша*» memorization

mutually exclusive relations *R1*, *R2*, *R3*, *R4*, *R5*. Based on these relations, the following operations Q_{rj}^{1}, Q_{rj}^{2}, Q_{rj}^{3}, Q_{rj}^{4}, Q_{rj}^{5} of information analysis and synthesis in NE1-4 are determined. A pair of vectors in NE1 is in relation to *R2*, the operation Q_{rj}^{2} is performed. A pair of vectors in NE4 is in relation to *R3*, the operation Q_{rj}^{3} is performed. A pair of vectors in NE2, 3 is in relation to *R5*, operation Q_{rj}^{5} is performed. There are no receptors in NE1 that perceive information belonging to the letter "*b*". NE1 is not excited. In NE4, part of the receptors perceive information that matches the letter "*b*". NE4 are excited in accordance with the number of matching signs of the letter "b". NE2,3 complete coincidence of parts of the signs of the letter "*b*". NE2,3 are excited to the maximum, connect with the nearest spontaneously excited NE5 and transmit information. As a result, the letter "*b*" is synthesized and memorized in NE5.

Further, at the learning stage, the letters «*в*» and «*г*» do not have a sufficient number of matching features with the letters memorized in the growing neural network and are simply remembered in NE 6.7 (Fig. 15).

Fig. 16 shows the process of memorizing the letter "*∂*". Analysis of the letter "*∂*" (Fig. 16-*a*). Synthesis and memorization of the letter "*∂*"(Fig. 16-*б*). On Fig. 17 a, b shows the process of memorizing the letters "*м*" and "*ш*".

Further, when memorizing the word "mother", the letters "m, a, m, a" are excited sequentially in time "t1 t2 t3 t4" Fig. 18.

Memorization of the word "masha" is shown in Fig. 19.

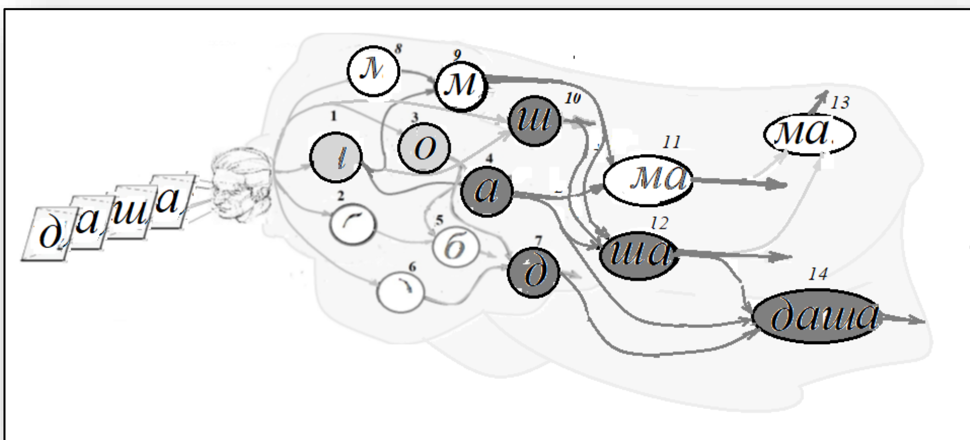

Fig. 20. Letter «*даша*» memorization

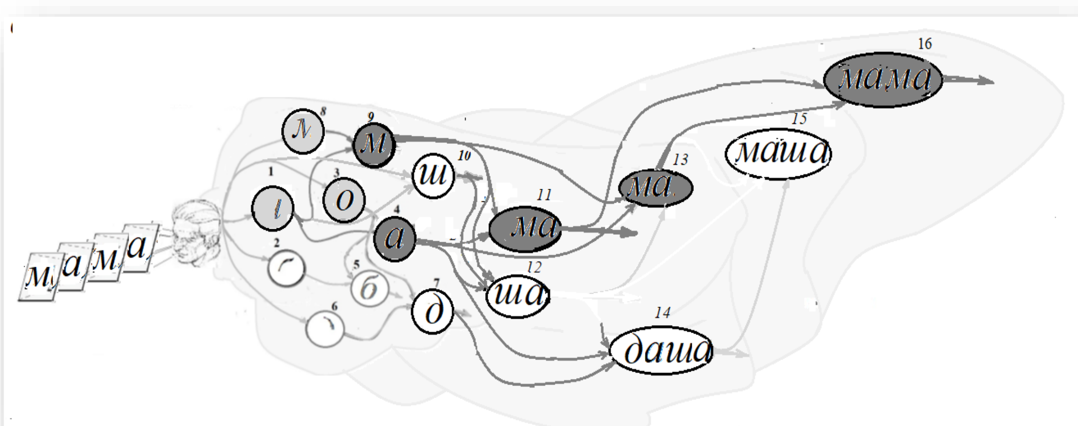

Fig. 21. Letter «*мама*» memorization

Memorization of the word "dasha" is shown in Fig. 20.

Memorization of the word "mother" is shown in Fig. 21. In this case, the analysis and synthesis of words take place. Similarly, there is an analysis, synthesis and memorization of sentences and texts. As a result, a multilayer neural-like growing network is formed (Fig. 22).

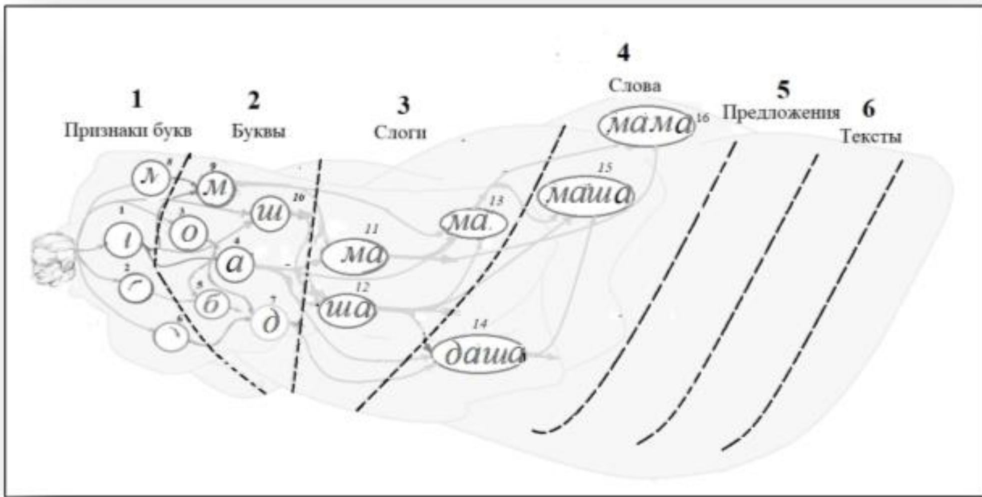

Fig. 22. Multilayer neural-like growing network

In this case, it has six layers: the first layer part letters, the second letter, the third syllables, the fourth word, the fifth sentence, the sixth text.

The process of analysis in the fifth and sixth layers of a neural network is the first step toward understanding the meaning of perceived information, but this is a subject for another paper. From the above examples, it can be seen that during the first perception, information is divided into separate parts during the analysis. With repeated perception, information is collected, from parts, or a new one is synthesized, which was not previously remembered. Hence the need for repetition in learning and memorizing new information. “Repetition is the mother of learning” is a proverb that confirms this rule. In the same way, various visual, tactile, sound, etc. information is remembered and recognized. Recognition and memorization of information occur simultaneously, and each access to the stored information can occur simultaneously with its updating and clarification. It is possible that the mechanism of operation of human brain neurons described here is not entirely accurate, but the operation of neural-like elements and a neural-like growing network in the "brain" of a humanoid robot or intelligent system is real and tested on models of the intelligent information system "Dialogue" and the system for recognizing various objects "Recognition".

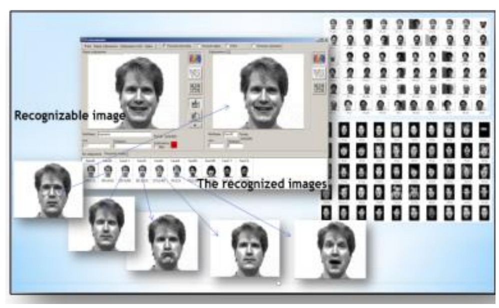

Fig. 23. Recognition of various objects

Fig. 23 shows the interface of the recognition system "Recognition" from the Yale

Fig. 24. Real-time recognition

University image database "Yale Face IMAGES_Data". The system model does not require high performance, huge amounts of memory and is created on a regular personal computer. There are more than 900 images of faces, letters, numbers, streets, etc. in the knowledge base of the system. Fig. 24 shows real-time recognition.

The system, a virtual robot, calls a person to itself. Captures a face image, memorizes, gets acquainted and then recognizes this person. Moreover, recognition and memorization occur simultaneously. If a person is familiar to the system, she recognizes him. If not familiar, then she gets acquainted and remembers. In contrast to today's popular deep learning networks, a neural-like growing network does not require huge training samples. Everything happens in real-time. I saw I remembered, I remembered I learned, I found out I corrected I remembered, etc.

In Fig. 25 the function of the movement of a simple real robot along a given route is shown. The robot is guided along the route.

Fig. 25. Motion function in real environment

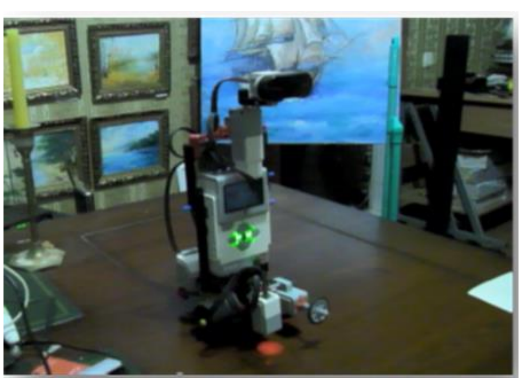

Fig. 26. The function of moving along a given route

Fig. 27. Reflex function. Collision with an obstacle

A neural-like growing network remembers the route. Then, when this section of the network is activated, the robot moves along the route.

In Fig. 26 obstacle reflex. The robot hits an obstacle (analogous to feeling pain). Remembers and no longer approaches the obstacle (analogous to the feeling of fear).

Fig. 27 shows the function "movement in a real environment - movement along the street. Khreshchatyk. At the beginning, the robot remembers the sequence of frames of the route of movement. Then, recognizing the sequence of frames, the robot moves along the route.

Conclusions

As a result of the studies of the work of physiologists in the field of the structure and functioning of the nerve cell, it was concluded that the memorization of information is carried out in the neurons of the brain and is associated with the synthesis of proteins, which is carried out in ribosomes based on the genetic information provided by messenger RNA. The structure and functions of ribosomes almost completely coincide with the structure and functions of a Turing machine, which is a simple device with an elementary simple set of operations. The Turing machine was invented in order to show the theoretical possibility of constructing an arbitrarily complex algorithm from extremely simple operations. Consequently, in addition to memorization, a nerve cell can carry out arbitrarily complex information processing algorithms.

There are more than 15,000 ribosomes in one nerve cell. One ribosome synthesizes protein at a rate of 15–20 amino acids per second. However, she rarely makes mistakes. Thus, the work of the ribosome is a highly precise process.

If we consider the ribosome as a molecular analog processor, *then the nerve cell of the brain is a molecular, analog supercomputer* that performs analysis, synthesis, processing and storage of information.

That information is stored in the nerve cells of the brain. Moreover, the memorization of information occurs as a result of the expression in the nucleus of genes that trigger the synthesis of new receptors in the cytoplasm, the geometric shape of which coincides in shape with the molecules released from the end of the synaptic neuron, which are actually sensory information describing the subject of memorization.

As a result of studying a biological nerve cell, a new model, a new type of neuron, a neural-like element, is proposed, which is the closest model of a biological neuron. The process of information perception by neural-like elements with the simultaneous construction of a growing neural-like network and their application in models of intelligent systems is shown.

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