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NEURON. MOLECULAR SUPERCOMPUTER

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Abstract. The article discusses the prospects for the development of intelligent computing systems. It is determined that at present the most promising direction in this area is based on the idea obtained as a result of biological research on the development of biocomputers, special types of molecular microcomputers using the concept of nerve cell DNA as the basis for calculations. In this regard, the structure and functioning of the nerve cell is considered in detail. 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 memory. In addition, it was assumed that the nerve cell of the brain is a molecular, analog supercomputer that performs the analysis, synthesis, processing and storage of information. Huge volumes of information perceived by a person from the moment of his birth and throughout his life are stored in a nerve cell. There are about 100 billion neurons in the human brain, with each neuron containing millions of membrane-bound ribosomes. A detailed consideration of the functioning of a biological neuron from the position of a cybernetic system approach led to the understanding that the structure and functions of the ribosomes of a nerve cell almost completely coincide with the structure and functions of a Turing machine. It is shown that, in fact, a Turing machine is a processor consisting of a logical device and external and internal memory. A neuron can be considered as a molecular multiprocessor supercomputer, since in a neuron, an analog of the logical structure of the ribosome, and external and internal memory are transfer RNA and informational RNA. An example of the implementation of the simplest version of the Turing machine is given. In conditions of successful development of this direction, the possibilities of computers of the future are enormous. A brief description of the neuron-like element and the neural-like growing network is given. Their application in the technology of molecular machines will lead to the creation of a machine brain similar to the human brain.

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

Introduction

In 1956, a seminar was held at Stanford University where the term Artificial Intelligence was proposed. In 1981, Barr and Feigenbaum proposed a definition for this term. "Artificial intelligence (AI) is a field of computer science that deals with the development of intelligent computer systems, i.e. systems with capabilities that we traditionally associate with the human mind - language understanding, learning, the ability to reason, solve problems, etc." Artificial intelligence is being developed on the basis of computing, which is constantly improving physical methods for creating computers, lamp, transistor and, finally, computers on integrated circuits. Currently, there is a tendency to approach the limit of semiconductor technologies and the emergence of computing devices operating on completely different principles. The nervous system of living organisms served as a prerequisite for the creation of intelligent computing systems, which makes it possible to efficiently process sensory information and solve control problems. On the basis of models of neural systems of the living world, neural networks and neurocomputers are developed, which are mainly focused on solving specific problems. Solving problems of different types requires the use of neural networks of different topologies. Emulation of neural networks is carried out - both in software on personal computers and supercomputers, and in software and hardware. Computer technology is developing at an extraordinary speed. Modern computers have almost exhausted the resources for improvement. In the near future, computers will change drastically, as the development of new technologies that have never been used before is already underway.

Approximately in 2030 - 2035 optical computers, quantum computers, molecular computers or biocomputers should appear.

Perhaps the most promising direction in the development of computing systems is based on the idea obtained as a result of biological research, the development of biocomputers. Biocomputers are special types of molecular microcomputers that use the concept of nerve cell DNA as the basis for computation.

Neuron

A neuron is a living nerve cell. Scientists from the Institute of Biophysics of the Academy of Sciences in Pushchino, using special filming, were able to see some fragments from the life of neurons. Neurons move like tiny amoebas. They are combined into groups and separated into individual neurons. They connect with each other and transmit information to each other. The more intense the work of the brain, for example, when solving problems or memorizing unfamiliar words, the more active the movement of nerve cells. Scientists joke that in order to solve complex problems, you need to actively move your brain.

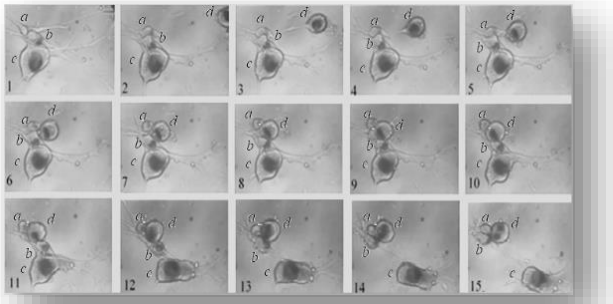

Fig. 1. Neurons

On fig.1 shows a storyboard of a video filmed at the Institute of Biophysics of the Academy of Sciences in Pushchino. Frames 1–10 show how one more neuron ***d*** joins the group of neurons ***abc***. A new group of ***adbc*** neurons is formed. On frames 11–15, neuron ***c*** leaves this group.

Neurons consist of the actual body of the neuron and processes - dendrites and an axon. Dendrites, the branched processes of a neuron, receive impulses from other neurons. An axon is a long process of a nerve cell.

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.

The structure of the nerve cell and its constituent organelles are shown in Fig. 2:
1. Axodendric synapse - the axon contacts the dendritic process of the neuron. *2. Axosomatic synapse* - the axon of one neuron contacts the cell body of another. *3. Presynaptic vesicle* - a vacuole containing a neurotransmitter. *4. Presynaptic membrane* - part of the surface membrane of the nerve fiber. *5. Synaptic cleft* - the space between the presynaptic membrane and the postsynaptic membrane. *6. Postsynaptic membrane* - a thickened surface membrane of the cell in the synapse. *7. Endoplasmic reticulum (ER)* (endoplasmic reticulum (ER)), consisting of many membranes on which ribosomes accumulate. *8. Mitochondria* are two-membrane organelles. *9. The Golgi apparatus i*s a complex network limited by membrane cavities. *10.*

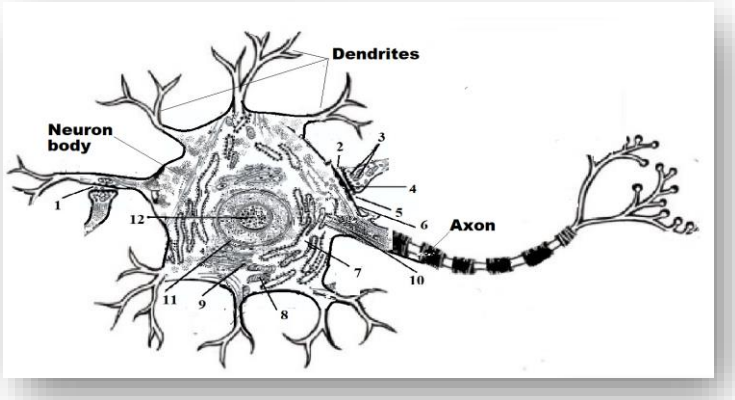

Fig. 2. Neuron cell structure

Neurofibrils - filamentous structures of the cytoplasm of a neuron. *11. Cell nucleus* - controls cellular processes and is the controlling

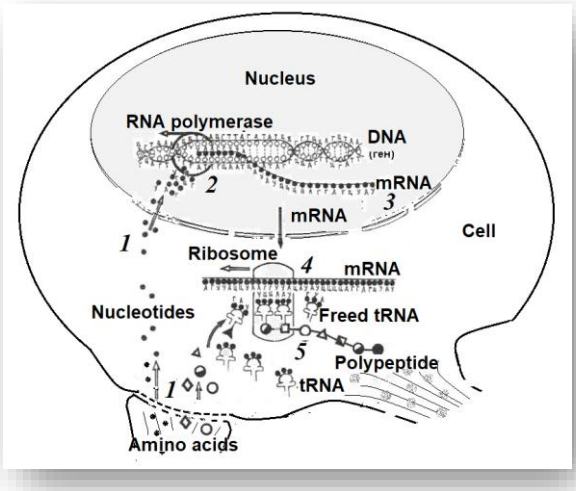

Fig. 3. Scheme of protein synthesis in the ribosome

center of the cell. *12. Nucleolus*.

In the structure of a nerve cell, from the standpoint of considering DNA as the basis for calculations, of particular interest to us is the endoplasmic reticulum, which contains many ribosomes that actually decipher the genetic information in DNA [1].

Ribosome. Synthesis of RNA and proteins

In the cytoplasm of the cell there are free ribosomes and bound ribosomes that are attached to the membranes of the endoplasmic reticulum. Ribosome - consists of a large 5 and a small 4 subunit (Fig. 3).

The main repository of information, instincts, unconditioned reflexes, and subsequent acquired conditioned reflexes is the deoxyribonucleic acid (DNA) molecule. The information stored in DNA is encoded in a special way. The DNA code is made up of four "characters", or nucleotides. These four types of nucleotides are designated by the letters A (adenine), T (thymine), G (guanine) and C (cytosine). In DNA strands, nucleotides are connected one after another in long chains.

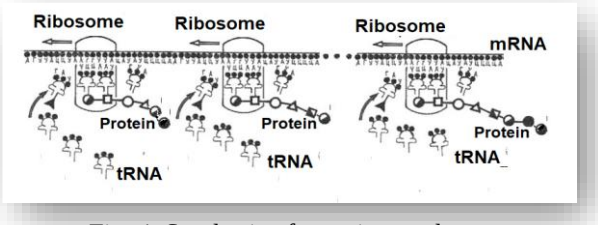

Fig. 4. Synthesis of proteins on the polysome

When nucleotides (external information) enter the cell nucleus 1 (Fig. 3). A special enzyme, RNA polymerase, binds to a DNA 2 molecule and creates a "mirror copy" - informational ribonucleic acid (mRNA) 3 or, as it is also called, messenger RNA (mRNA), which freely moves from the nucleus to the cytoplasm of the cell. Each mRNA is made up of four different nucleic acids, the triplets of which make up codons. Each codon specifies a specific amino acid. There are 20 amino acids in the body of all living beings on Earth. The codons used to specify amino acids are almost universal. The codon that starts all proteins is "AUG", the sequence of nucleic bases: adenine; uracil; guanine. The small subunit reads information from messenger RNA 4. A special molecule transfer RNA (tRNA) supplies amino acids for synthesis. The large subunit attaches an amino acid to the synthesized protein chain 5. The transfer RNA carrying the corresponding amino acid approaches the active codon and associates with it. A peptide bond of a new amino acid is formed with the protein under construction [2-4].

Protein is synthesized. In cells, the composition of the ribosome can change, and these changes depend on the state of the external environment. With the help of the most modern technologies, it has been established that mammalian cells contain ribosomes of different compositions. It turned out that in the same cell there is not one heterogeneous[1] population of ribosomes, but several such populations at once!

[1] Heterogeneity, that is, the selectivity of ribosomes in relation to mRNA, which leads to the synthesis of only some specific proteins encoded in mRNA molecules "selected" by the ribosome

They do not replace each other, but coexist simultaneously. Each of the populations translates only a certain set of mRNAs. This means that ribosomes are not universal. Separate groups of ribosomes interact only with certain mRNAs and, therefore, are "responsible" for the synthesis of only a part of cellular proteins [9]. Protein biosynthesis in a cell does not take place on one ribosome. As a result, a complex of ribosomes is formed, which simultaneously and independently of each other participate in the synthesis of protein molecules using the same mRNA. This complex is called a polyribosome, or polysome (Fig. 4) [5,6].

Thus, the information contained in mRNA is simultaneously translated by many ribosomes, and several protein molecules are synthesized in the cell, which significantly increases the rate of translation. As a result, ribosomes synthesize protein from amino acids based on the genetic information of DNA. Those. contribute to the realization of the hereditary information of the cell and ensure the uniqueness of each type of organisms due to the formation of proteins specific to it.

The structure and functions of the ribosomes of the nerve cell almost completely coincide with the structure and functions of the Turing machine.

Turing machine

Schematically, the Turing machine is shown in Figure 5.

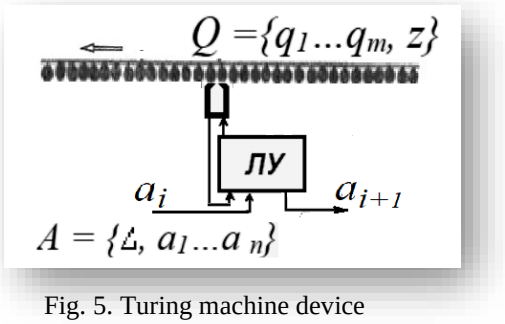

Fig. 5. Turing machine device

The machine operates in an arbitrary finite alphabet $A=\{0,1,...,9,\Delta\}$, - 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). A LU can be in one of the states that form a finite set and are denoted by $Q = \{q_1...q_m, z\}$, (similar to mRNA in the sense of an analog with ribosomal protein synthesis), moreover, state z (analog 3') corresponds to the completion of work, and q_1 (analog 5') is the initial (original). $A=\{0,1,...,9,\Delta\}$, 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 supplied 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 (tRNAs are lined up against mRNA on the ribosome. 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 to the problem of adding 1 to the number n in the decimal number system. We use the external alphabet $A=\{0,1,...,9,\Delta\}$, in which the symbol □ corresponds to an empty character. 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.

Here 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

256 +1 = Initial configuration *25q6*

Takt 1. q6→z7S, i.e. 6 will be replaced by 7 and stop will occur with the final configuration 2z57, i.e. the result of addition is 256+1=257.

219 + 1 = Initial configuration 21q9.

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

Takt 2. q→1 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.

999 + 1 = Initial configuration 99q9.

Takt 1. q9→ q0L, i.e. an intermediate configuration 9q90 will be formed.

Takt 2. q9→ q0L - configuration q900 will appear.

Takt 3. q9→ q0L - q 000 will appear.

Step 4. q z1S - z1000 will occur and work will stop.

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 [7].

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, a population of ribosomes coexist simultaneously and implement different algorithms). In fact, a Turing machine is a processor consisting of a LU, and external and internal memory. In a neuron, ribosomes are an analog of processors, and external and internal memory - tRNA and mRNA. Then the neuron can be considered as a molecular multiprocessor supercomputer (MMS).

The Turing machine is extremely simple in design. It has an elementary simple set of operations. A significant advantage over conventional computers is that access to memory cells (tape sections) in it occurs not by address, but by sequential movement along the tape. At the same time, this is also a disadvantage. for this reason, such operations as adding or comparing two symbols 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. However, the huge number of ribosomes involved in this process (massive parallelism) nullifies this disadvantage. Therefore, if its device is organized by analogy with the device of a neuron, then such an architecture receives significant advantages over classical CM.

Machine brain

The human brain contains about one hundred billion neurons, one hundred billion molecular multiprocessor supercomputers, united in a highly complex neural network, which is formed and changed every second in the course of a person's life. To create a machine brain similar to the human brain, it is necessary to develop a new type of artificial neuron.

The neuron is the most elementary and at the same time complex system. Considering the functioning of ribosomes in a nerve cell from the standpoint of a cybernetic system approach, it was possible to develop a new type of artificial neuron.

A neural-like element (NE) is a model of an artificial neuron that is closest in analogy to a biological neuron. A neural-like element is the main component of neural-like growing networks and consists of a device (analogous to the cell body) with many excitatory, inhibitory, and modulating inputs (dendrites) and one output (axon) [8].

Neural-like growing networks (n-GNs) are the basic structure of the theory of artificial intelligence and the perfect model of biological neural networks. Neural-like GN are a homogeneous structure consisting of receptor and effector zones, in which, by modeling the basic law of biology - the unity of the organism and the environment, carried out on the basis of the unconditional reflex activity of the nervous system, knowledge, forms of behavior and performance of actions are acquired and accumulated in accordance with with the conditions of the external environment. Neural-like growing networks are dynamic structure that changes depending on external information entering the receptor field and information generated by the effector zone to the outside

world. The perception, analysis, synthesis and memorization of external information is accompanied by the excitation of new neuron-like elements in the network and the connections between them in the receptor zone, and the generation of actions, behavior and adaptation to changes in the outside world is accompanied by the excitation of new neuron-like elements in the network and the connections between them in the effector zone. The process of excitation spreads in waves through the network [9].

Combining a lot of mmS into a neural-like growing network, we get a machine brain similar to the human brain.

DNA computer

A special case of the Turing machine is already a reality! In 2001, a group of Israeli scientists led by Professor Ehud Shapiro from the Weizmann Institute of Science published an article in the journal Nature on the topic of conducting research on the creation of molecular computers. They demonstrated that simple programmable computing devices created on the basis of DNA and capable of working inside a living cell have become an objective reality. Currently, the computer developed by the Shapiro team implements a special case of a Turing machine: a two-state automaton with a two-character alphabet. The automaton is able to answer simple questions about the contents of lists containing two types of characters, such as "0" and "1" or "a" and "b". For example, is the number of ones in the sequence even? Or is there at least one character "b" in the sequence? [ten]. If success is achieved in this direction, the possibilities of future computers are enormous.

3. Conclusions

The article considers the prospects for the development of intelligent computing systems. It has been determined that at present the most promising direction in this area is based on the idea obtained as a result of biological research on the development of biocomputers - special types of molecular microcomputers that use the concept of nerve cell DNA as the basis for calculations.

Based on the consideration and analysis of the work of neurophysiologists 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 memory. A detailed consideration of the functioning of a biological neuron from the position of a cybernetic system approach led to the understanding that the structure and functions of the ribosomes of a nerve cell almost completely coincide with the structure and functions of a Turing machine. A neuron can be considered as a molecular multiprocessor supercomputer**.**

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