Application of Cellular Automates in Some Models of Artificial Intelligence

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The problem of modeling many natural phenomena is too complex and requires interaction on different scales. Here we show that one of the possible and convineient way to approach this problem with hierarchical cellular automata. The peculiarity of this approach is that the state of the cell is modeled by another cellular automaton with as many recursive layers as needed. We make an example of how the "Smart cube", as we called it, can be used for simulating such a complex system as the brain. Different levels from neurotransmitters to large-scale neural population interaction can be represented into one model of cellular automata. Furthermore, this allows to experiment with different learning rules and incorporate many interesting mechanisms like anticipation.

Keywords—brain modeling, cellular automata, self-organization, "smart cube", anticipation

I. INTRODUCTION

Modern theoretical physics is an important source of ideas. As an example, we can call quantum mechanics, in particular, path integrals, operational approach, category theory, and so on. Also important are the concepts of statistical physics, ensembles, probabilistic description, network structures. In addition, new descriptions appear all the time, which more accurately reflects the structure and behavior of natural objects - first of all at the micro level. Among the relatively new approaches to the description of physical objects should be noted cellular automata. Apparently, for the first time in explicit form, such an approach was applied in physics to the largest structures of the universe by the German experimenter K. Zuse (1942), and extended by many scientists (see [1, 2]). At the micro (quantum) level, you can mark studies [3-6]. We note that now such (or similar) models have begun to be applied in approaches to the theory of gravity [5]. Also, recently appeared cellular automaton models, which take into account the property of anticipation (accounting of future space of the system) [7]. Note that even at the specified micro and global levels (quantum and universe), even classical cellular automata lead to a new understanding of nature. But between these "extreme" levels, as system analysis teaches, there are still many levels in their hierarchy and the study of cell models for these levels gives new knowledge about the behavior of systems. Moreover, specific new features of systems behavior at these levels can then be transferred to the basic micro and global level and lead to new challenges and new knowledge sets for both micro and global levels.

In the proposed work, we present new possibilities of cellular automatoes in the study of several levels associated with the functioning of a real-world complex system - namely, the human brain. The results of the new model architecture ("smart cube"), the process of studying the relationships of such models, the definition of the role of anticipation and the ability to transfer the properties of the brain on the micro and global level are presented.

II. GENERAL PROBLEM OF CELLULAR AUTOMATES USING IN BRAIN STUDIES

The concept of cellular automata (CA) was developed in the 40's of the 20th century by S. Ulam and J. von Neumann. The main motivation for the introduction of a spacecraft was the study of parallel computing, as well as simulation of the work of the brain. According to the authors' plans, this would allow the creation of an artificial system that would solve extremely complex tasks. The construction of such a system remains relevant today. For more than 60 years, the study of the CA, formulated the basic principles of their work and it became clear that with their help can solve a wide class of problems [1]. It is now believed that CA is a good tool for simulating different processes, mainly where there is the interaction of a large number of discrete elements.

The work of the CA is based on the basic idea: "the basis of complex processes is simple rules for the interaction of simple elements". In modern science, this idea can be attempted to expand into at least three huge areas: on the physics of elementary particles, on epigenetics and on neuroscience. Speaking of elementary particle physics, in 1965, in his work, Feynman put forward the hypothesis that "ultimately, physics will not need mathematical expressions, at the end of the machinery will be discovered and the laws will turn out to be simple as a board for checkers with all its apparent complexity -this "[2].Since then, there have been many theories that attempt to describe the universe as a set of discrete elements. Works by K. Zuze, E. Fredkin, S. Wolfram and others lay the foundations of discrete physics. In particular, t'Hooft points out the possibility that quantum effects may have a deterministic nature [3]. Also, it may be possible to apply the idea of CA in the epigenetic region where there is an incredible complexity of mechanisms for regulation of gene transcription, as well as a large variety of these mechanisms. One of the central tricks of present science is the human brain. New research methods and a large number of scientists in this area caused a huge increase in information about the nervous system. So is the detailed model of the work of the neuron - the model of Hodgkin - Huxley. There are also many derivative models that also quite well reproduce the dynamics of the neuron, and are computationally more efficient, such as the Izhikevich model or the exponential-on integra-active model [8]. Different models of transmission of the potential of action appeared, in particular models of synaptic plasticity, for example, the rule of time-dependent, ductile adhesion. Much is known about the relationships between neurons, which form the basis of memory. But there are many problems. The basic of them is to summarize all the information and to understand how the neural networks, which are the basis of memory and behavior, are formed in relation to the rules of interaction. That is, there is no global theory of how the brain works. One of the main theoretical methods of research was computer simulation. Modern models of neural networks number millions of neurons [8], and as there are no mathematical methods for studying such large systems,

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simulation is used. This sub-process uses the knowledge we have and tries to find out what can be obtained from this. For the past 20 years, many models of neural networks have been proposed, but progress in this direction is slow. For example, "Liquid state machine" models a neural network with a realistic neuronal dynamics and uses different training rules. Such a mechanism is capable of elementary computational operations, but there is a lack of understanding of how to leap to real neural networks of the human level, leaps to more functionally complete neural networks.

To make such a leap, of course, you need to further explore the real systems, but also need new theoretical studies, with new models, with new principles. Here you can use the CA approach. Looking at the knowledge of neuroscience, choose the rules of dynamics and interaction of cells in the direction of the desired behavior of the system as a whole. Also, here you can include frequency models of neural networks with the corresponding rules of plasticity, for example, VSM. And most importantly, it is trying to ask relatively simple rules of dynamics and interaction with cells, the minimum manual design of the system, to ensure the possibility of self-organization.

If, using the idea of the work of the cellular space, it will be possible to reproduce in the cellular models the dynamics and the functionality of real neural networks.

III. Some general principles of functioning

Recently, many models have appeared, in which different rules of interaction of neurons and their internal dynamics are presented. These models are trying to recreate activity and, if possible, brain function. But the problem remains to determine and take into account all the requirements for modeling and the principles of the work of the cerebral cortex. Models may be based on adhesion neural networks or cellular automata or on other approaches, but regardless of the approach should be imposed some restrictions derived from neurosciences. Previously, principles have been proposed, the necessary aspects that should be present in such models, which include the possibility of modeling not only activity but also the study of the processing of information by the brain. These requirements and general principles are scattered across different jobs and should be collected, possibly supplemented, and some modified.

If you try to formulate the principles in general, then they include:

• the need for both local and long-distance links,

•three-dimensional model - continuous learning - autonomous activity,

•sparse-scattered representation of cell activity.

You also need to consider the presence of the basic unit of processing infomation - cortical column. The work of such unit generates the superficial plasticity of the cerebral cortex and provides its relative one-native lateral direction. Another conclusion is drawn from this fact - the absence of explicit input and output. That is, when submitting to any part of the system of input data, the system must adapt and change the structural relationships. These links are formed to reflect the statistical characteristics of the stimulus: the more a given stimulus is presented, the stronger this is reflected in the bonds. In order to take into account the timeliness of the stimulus, such as consistency and duration, attempts are made to use autonomous activity of the network. Thus, the system at should takes into account not only the external stimulus, but also adds to its internal state, which is determined by the background and previous incentives.

As a tool for modeling a system that would satisfy the above-mentioned principles, the method of cellular automata is appropriate. In a cellular automaton, it is convenient to experiment with the connections between cells and the rules of their formation. If the cell simulates a neuron, then the dynamics can be given by the usual adhesion model of the neuron. If the cell simulates a more complex object, it is convenient to present the dynamics as the dynamics of the embedded cellular automaton. So, if the system tries to model the brain, then there are many hierarchical levels that correspond to zones, columns, or individual neurons.

IV. Architecture of the model in the light of three-dimensional cellular "smart cube"

For modeling of complex objects such as the brain, using a cellular automaton it is convenient to present the dynamics of a cell in the form of the dynamics of another cellular automaton. Such a three-dimensional hierarchical system provides flexible management of parameters and rules of interaction on different scales. Let an arbitrary cell $(i, j, k)_p^l$ be of classes, where l is the level of the hierarchy, p - the reference to the parent cell of the upper level. The level cell of the level l determines the enclosed cellular automaton, or due to the attraction to a certain attractor, either through the average activity, or else through the path. The hierarchy does not have to be homogeneous and may vary from cell to cell, with its topology, ties, rules, and internal states. The number of levels is arbitrary and is determined by the parameters of the simulated system. A simple example of a three-level CA system with the same cubic structure is presented in Fig. 1

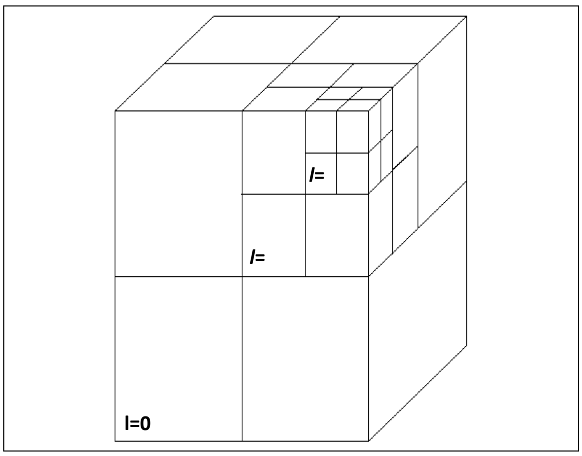

Fig. 1. Three-level hierarchical system of spacecraft with the same cubic structure.

Such a cellular automaton can be adapted to various real objects. Consider an example of adaptation to the structure of the brain. We introduce the base level ($l = 0$) - a cellular automaton in the form of a cube, a level of neuromodulation-torus. Since the hierarchy may be heterogeneous, we will enter level 1 of two t-half. The first type is "bark", a two-dimensional cellular automaton, and a level of cortical columns. The second type is "volume", the level of subcortical structures. It is assumed that the second type consists of many modules that can be developed independently of each other. We introduce level 2 in the "cortex" - one-dimensional cellular automaton, level of the cortical layer. Finally, level 3 is a three-dimensional cellular automaton, a level of a neuron. Thus, the architecture of the cube with a "bark" on the edges comes out, where cortical columns, layers and neurons are represented. The "volume" type includes various modules that, although they can be developed independently and add a campaign hunt, but must create different connections with other modules and bark. If there is a need for complication of architecture, then you can enter the level of geometry of the neuron, which takes into account the shape of the dendritic tree, and the level of neurotransmitters, to simulate individual synapses. Basically, the inputs and outputs in the system are given at the cell level - the neuron, but other options are also possible in the study of various parameters. The setting of such a cellular automaton structure is a matter of convenience for experimenting with the rules of interaction. The issue of training neural networks is most relevant in modern neuroscience, so this hierarchical machine can serve as a good platform for testing rules of plasticity.

V. TRAINING "SMART CUBE"

The search for rules of plasticity can take place in two directions – downward and bottom-up. The top-down approach involves observing the activity of the neural networks in general and an attempt to recreate the rules of interaction that would play such an activity. In this direction, automated approaches to the selection of rules are usually used, for example, the use of a co-evolutionary approach based on genetic algorithms. By using the EEG data, you can select the necessary rules to reproduce brain activity. A characteristic feature of cellular automata in this case is their ability to accurately reproduce the given pattern when scaling. But it is doubtful whether indeed, if the activity is globally relatively accurately determined, then the mutually-determined mode on the local one is correctly defined. Therefore, the bottom-up approach is more promising. It is based on experimental data of behavior of neurons and molecular mechanisms of their vital activity and interaction. On the basis of these data, there are quite a few models that try to explain one aspect or another of the functioning of the nervous system. For example, when modeling the interaction between cortical columns, the WTA model (Winner takes all) is often used (Winner takes everything). Such a model is based on the interaction of activating and suppressing neurons, resulting in the neuron, which is most susceptible to a particular stimulus, wins due to competition. The winning, in this case, means responsibility for coding a particular stimulus by enhancing the corresponding activating links.

For modeling at distant distances, rules similar to the Hebb's rules are used, the most popular of which is the rule of adhesion-time-dependent plasticity. But, if such rules code the spatial characteristics of the stimulus, then it remains unclear how the characterization of the time-dependent characteristics, such as the duration of the stimulus and the different sequences, occurs. There is no noticeable progress in this direction, but there are ideas how it can be realized. One of these is the calculation depending on the state of the system. According to her, when giving an incentive to the network there is activity that develops and after the termination of the stimulus. When submitting a new stimulus or the same state of the network will be different, this state takes into account the previous history of activity. As a result of such activity development, when certain rights are specified, it will be possible to realize the memory of the information in the network, such as how it occurs in humans. What these rules are not exactly known for, and therefore, in this case, the three-dimensional hierarchical cell automaton described above can be used. In it, naturally, there is no autonomous activity, therefore it is easy to experiment with different clasters of plasticity. In addition, in the theory of cellular automata, there are some studies to find the rules of the evolution of automata from the results of the behavior of automata [9].

In general, we can not say that it is necessary to use the hierarchical cellular automaton instead of other approaches. But this approach provides relatively greater convenience and flexibility in research, as it reproduces the natural organization and the relationship between structural elements: synapses, neurons, cortical columns, and others.

VI. TAKING ACCOUNT OF ANTICIPATION EFFECTS IN THE PROPOSED CELLULAR AUTOMATES

Absolutely new possibilities take into account anticipation in the proposed cellular automata. In this case, the transition of cell states from one moment to the next takes place taking into account all possible virtual states of the cells at the next moments of time. The simplest illustration of the emerging features is the well-known game of "life" of J. Conway, but with the introduction of advance [10]. The main new effect is the possible ambiguity of cell states with the selection of each time a single state as the value of the results of the observation. Incidentally, this allows us to look at the phenomenon of consciousness as a process of choosing from possible variants.

VII. CONCLUSIONS

The patterns and effects presented in sections 2-5 are already interesting for considering these levels in the hierarchy (that is, for processes in the brain) and can be used as models. The detailes of the models and the results of computer modeling requireres much more space and will be presented in presentation and separate papers. But as noted in the introduction, the phenomena and legality that can be found at these levels, you can try to move on the micro and global level. Here are just a few remarks.

1. Since cellular automata (especially with anticipation) can be used for the search for manifestations of consciousness, one can ask questions about manifestations of consciousness in cellular automaton models (and even in nature) on the micro (quantum) and global (Universe) levels.

2. Section 4 describes the possibilities of applying learning processes to determine the rules of changing cell states in cellular automata (in fact, to find the rules of evolution of cellular automata in their previous behavior). For micro and global levels, such training means identifying (constructing) approximations to the rules of the evolution of systems. Actually, one can raise the question of the emergence of rules (laws) of nature, at least in terms of the observer. Probably this correlates with the emergence (birth) of the laws of nature in the zone of the Big Bang, with subsequent stabilization over time.

3. The cellular automaton (classical) can be regarded as a kind of transformation of information (moreover, even in the spirit of modern theories and approaches to the birth, transformation and role of information in the family as a whole (see [11]). The results of the previous sections, especially taking into account the anticipation, allow in principle to return to such questions at the micro and global levels, taking into account the possible polysemy.

Thus, the paper considers new possibilities of research of some problems of physics, theoretical physics and artificial intelligence modeling with the use of cellular automata. Especially useful roposed approach may be for investigation of processes in real brain.

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