The Movable Cellular Automata as a Tool to Simulation Biological Process and Systems

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Рухомі Клітинні Автомати як Інструмент Моделювання Біологічних Процесів та Систем

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***Abstract*—There is a simulation of the biological process and systems using the movable cellular automata**

***Анотація*—У даній роботі розглянуто моделювання біологічних процесів і систем методом рухомих клітинних автоматів**

Ключові слова—рухомі клітинні автомати, моделювання біологічних процесів, штучні нейронні мережі

Keywords—movable cellular automata; simulation biological proces; artificial neural network

I. INTRODUCTION

Recently the trend of computer simulation related to various aspects of the organization and functioning of biological systems is actively developing. The range of objects for modeling is quite wide - from elementary processes of self-replication [1] to the dynamics of multicellular organisms and nervous subsystem [2]. Typically, the implementation of these models is very complicated task. To realize the full potential of this field, it is essential to use the heritage and make connections with such sciences as biology, the theory of algorithms, cognitive systems, adaptive systems, robotics and others. An important component in modeling of biological processes and systems is artificial neural networks (ANN) or their equivalents, since it enables learning and adapting components of artificial organism to changing environmental conditions.

II. PREVIOSLY INVESTIGATIONS

The interesting approach to the problem of artificial life simulations is a 'Gene Pool' project created by Jeffrey Ventrella [4]. Gene Pool is a virtual Darwinian Aquarium where the user witness evolution unfolding before users eyes. Mate selection criteria can be tweaked to see what happens when "fat" or "immobile" or "long" are considered beautiful - even if these attributes run counter to having the anatomy and motor control for efficient swimming. This simulation has no goal or win and lose but the user can make up goals for instance to breed the fastest swimmer or try and breed two types of swimmers which can coexist in harmony.

Other concept of multicellular development [5] to evolve bodies and controllers of soft-bodied animats, evaluated within simulated physics environment. Growth of an embryo is driven by a neural network-like controller in every cell. The authors shows how, through an evolutionary process, this simple approach produces rich and complex morphologies of animats made of hundreds of cells and exhibiting life-like gaits without centralized control. They then show how the system allows us to evolve animats that optimize both for distance and the use of actuating material, and demonstrate how it can be used to evolve developmentally plastic individuals, whose genomes encode more than one phenotype, each adapted to a different type of environment.

In the paper [6] authors have investigated how the concept of metamorphosis can enhance artificial developmental processes used to evolve designs of robotic morphologies and controllers. Metamorphosis allowed to evolve solutions in which a single genome encodes two related phenotypes, each crafted for a different problem and/or environment, together with a method of self-restructuring one phenotype into the other. Given a biologically inspired model of development, this required simply employing a fitness function that rewards each developmental stage for a different objective. It was observed how evolution and searching for morphologies de novo, without any prior assumptions about what they should be, was able to discover designs that are well adapted to different tasks at each stage of development. Reversing the order of environments in which growing individuals were evaluated allowed us to confirm that observed morphological changes were clearly a result of evolution shaping growing morphologies in a convergent way: legged locomotion for a terrestrial environment and undulatory swimming for an aquatic one, regardless of the order of evaluation. A further comparison with the evolution allowed finding that metamorphic individuals indeed produced useful specialization, outperforming environmentally robust solutions.

Other interesting approach for the evolution of multicellular animats can be observed in the [7]. In this article was presented a model of parallel co-evolution of development and motion control in soft-bodied – multicellular animats without neural networks. Development is guided by an artificial gene regulatory network (GRN) with real-valued expression levels, contained in every cell. Evolution was successful for generating moving animats and discovering several functional locomotion strategies. Motion was controlled through coordinated cell actions, where individual cells displayed emergent periodic patterns of expansion and contraction. The animat model used in this paper, a collection of springs modifying their resting length, is similar to a model of a soft-bodied robot.

A very interesting approach is morphogenetic robotics by Jin and Meng [8] examine methodologies for designing self-organizing, self-recongurable and self-adaptive robots inspired by biological morphogenesis. They categorized these systems into three main areas: swarm robotics, modular robots and body-brain co-design, and discuss their relationships with epigenetic robotics, which deals with cognitive development, and evolutionary robotics, which is concerned with the automated design of controllers. In their investigation they follow broad distinction between "swarm" and "modular" robots, keeping focus on morphogenetic abilities, and with the additional limitation to small-scale and exact-t construction systems. In a third subgroup, they described nonrobotic block structures, whether made by external "worker" robots or arising spontaneously from physical interactions.

Complex self-reconguration and locomotion tasks are shown M-TRAN system [9] is a well-known self-recongurable modular robot. Their robotic unit mechanical design was simpler and yet capable of more complex movements than other models such as crystalline atoms. The shape of this unit is anisotropic with two rotational degrees of freedom. The authors fully implemented the physical robots and successfully demonstrated intriguing behaviors, including snake-like locomotion, caterpillar track, quadruped walk, obstacle avoidance, and dynamic self-transformation among those shapes or behaviors.

Modular robots that can demonstrate complex behaviors including self-reconguration and self-reproduction were developed by Lipson with his lab. [10]. Their robotic unit, called "molecube", is a cubic module with only one rotational degree of freedom that swivels two halves of the cube around a diagonal axis. The architecture of the system becomes even simpler and more programmable than earlier models. Using this framework, scientists of this lab demonstrated self-reproduction and self-repair of simple morphologies, as well as evolutionary acquisition of novel forms in a simulated universe.

Based on the theoretical knowledge, a new class of systems collectively called artificial embryogeny (AE, sometimes "artificial ontogeny" or simply "artificial development") was appeared. This direction of science develops well among others through the works and reviews of Miller and Banzhaf [11], or Stanley and Miikkulainen [12]. Inspired by the biological development of multicellular organisms, AE systems realize the indirect mapping from genotype to phenotype via more or less complex developmental stages. In this investigations proposed codding the parameters of the genotype code for microscopic features of the cells (the agents), i.e. their abilities to communicate, their propensity for motion, and their affinities for assembly with other cells, instead of coding directly for macroscopic features phenotype (the system). Like biological cells, the agents of an AE system generally share the same genotype, i.e. the same set of developmental and behavioral rules. Imitating cell division, differentiation and self-positioning, an agent spawns other agents, follows its own execution path within the common program which may diverge from its neighbors' path depending on its position and creates specific links with other nodes according to its fate.

Particular attention should be given to the shaping of artificial neural networks in the literature. Structured ANNs can provide highly interesting auto-teaching structures as mentioned by Nolfi in [13]. "Auto-teaching networks" consist of two subnets, a "teaching network" and a "controlling network". The authors describe, that such a network, if it is shaped by an artificial evolutionary process, has "genetically inherited predispositions to learn". The virtual embryogenetic approach described in this section aims for the evolution of neural networks with substructures with this ability.

Another work that deals with the problem of differing functions within an ANN is [14], in which different predispositions for learning are implemented by "virtual adaptive neuro-endocrinology". Within such a network, different types of cells exist: gland-cells, which influence the learning of the network, and regular cells, which are influenced by the gland-cells.

A different approach to shape the structure of an ANN has been described in [15]. In the system described, the position of the cell is fixed from the beginning, the growth of axons is controlled by morphogenes diffusing throughout the embryo. The advantages of this system seem to be the higher tendency for self-similarity of network structures during evolutionary processes, but on the other hand it seems that it has a low probability to develop differentiating cell-types with different functions.

III. THE SIMULATION OF LOCOMOTION

In this paper it is suggested to use moveable cellular automata (MCA) as a tool for modeling various biological processes and systems. As it is known, these computing structures are characterized by its simplicity, versatility and possess natural parallelism. Important advantage of the MCA method is a possibility of direct simulation of materials fracture including damage generation, crack propagation, fragmentation and mass mixing. In the case of modeling biological processes and systems, complex metabolic processes that occur in living systems can be presented by the appropriate exchange of contents of the MCA nodes, the synthesis of tissue – by division of the nodes, dying – by removing of the nodes, muscle contraction – by reducing the distance between the nodes etc.

In particular the simulation of a process of locomotion of life-like organisms [16], the simulation object is divided into two subsystems – mechanical and neural.

Mechanical subsystem represent the corresponding nodes of MCA of organism and simulates different body tissue i.e. muscle, connective, nervous. The scheme of cellular automata algorithm is asynchronous. It provides a random convenience sampling of one CA from the set and the appropriate modification of its state and the state of its nearest neighbors according to the rules of interaction. After interaction finishes another MCA is chosen randomly and the process is repeated. A signal for cellular automata interactions is the state of the corresponding "nerve ending" of the neuron subsystem that is associated with corresponding CA.

During the simulation of a neuron subsystem the elementary analogues of artificial neurons (perceptrons) are implemented. Their basic task, similar to that of biological neurons, is to form output signals guided evolutionally algorithm, according to the set of input signals, their state, and the function of transformation. For every separate CA the coordinates of remote fragments of the designed organism are pointed out, the states of which are input signals for the corresponding neuron. Thus, input connections appear chaotically. The amount of connections is fixed for all CA.

Arbitrary evolutionary algorithm shows the random changes (mutations) of parameters and estimation of influence of these changes on the dynamics of the system according to a corresponding criterion. If a criterion is satisfied, changes are fixed, otherwise they are rejected, and that is the complete analogue of natural selection. The criterion can constantly change during the existence of the body, from reducing energy consumption during the locomotion, achieving the maximum speed, the struggle for survival up to adaptation to new environmental conditions.

This approach works well in the absence of growth of the organism and "reversible deformation", since neighboring cells and the connections between them remain unchanged.

IV. THE GROWS PROCESS

Much more complex modeling process is associated with the ability of the organism to grow or change shape in the process of adaptation. In this case, cell shift occurs, or connections between them change within the body.

In concept of virtual growth, which is considered here, we are mimicking processes observable in biology during the developmental phase of most multicellular life-forms. We also included general concepts of biological embryogenesis and artificial embryogenesis [17]. The fast calculation of single embryological processes is necessary, due to the requirement for fast simulation of embryological processes on systems with limited hardware resources, especially for projects dealing with evolution in autonomous robotic systems

During the process of artificial growth of the organism, the embryo is considered as the cellular automata field of separate cells linked in some way. The cells of embryo can reproduce itself, die, acquire a certain type, build connections with other cells of the embryo. An important aspect of this model is that the cells do not have the ability to move actively, but can be "pushed out" from their spatial position during the growth (duplication of other cells). The growth of the embryo (and thus built artificial neural network) is subject to the outcome of the process of self-organization. The process of growth of the embryo is considered complete when there is no more cell duplication or cell death over a long time span. It should be noted also that the cases of infinite growth of the embryo or its complete disappearance are possible. In connection with these "pathological" forms of embryo growth, it is necessary to stop the process if the number of cells exceeds (in the case of infinite growth) or is less than (in the case of death) certain prescribed limits.

After the process of growth stops, the cells and relevant links between them undergo a detailed analysis. It is clear that the cells, which were neighbors at an early stage, can significantly move away from one another. In this case, there is

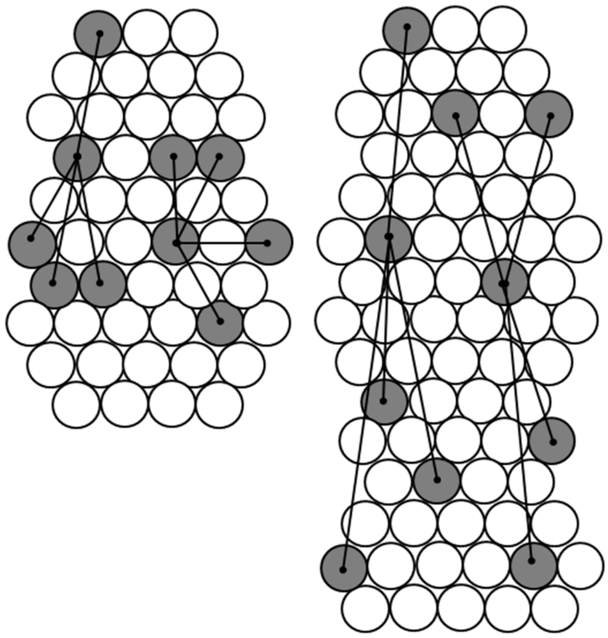

Fig. 1. An example of connection between cells before (in the left fig.) and after (in the right fig.) some period of process of organism's grows.

a problem of constant search for the nearest neighbors, and establishing ties between them.

The method of search of the nearest neighbors under the conditions of their fixed quantity is described in the papers [18]. In this work, the criterion of the neighboring cells search is the minimum distance between them, and the search is carried out by introducing auxiliary index array. The suggested algorithm showed good results for both uniform and random distribution of cells in space. A significant advantage is speed and low need for computing resources that is important in the development and operation of processes connected with the evolution of autonomous systems, as mentioned above.

V. CONCLUSIONS

This paper provides an overview of works in the field of modeling biological processes and systems as well as fundamental approaches to solve problems of interaction between cells in multicellular organisms.

Study of the works of the famous scientists in this field enabled conceptual and technological breakthrough for achieving extended reliability, advanced adaptability and artificial evolution. It is a main tool for sustainable development for the next generation of collective robotics and adaptive autonomous systems. Based on this investigation, artificial organisms reflect many similarities with biological organisms. This, in turn, opens a way for many great ideas, like artificial sexuality or inspiration from “natural chemistry”, which may seem speculative at this moment, but are very promising in terms of their biological analogies. Since the research should be focused on the specific goals, many of these ideas will be not followed further till their development into the real systems.

As a method for modeling the dynamics and development of bio-organisms, the method of movable cellular automata was chosen. Significant advantages of this method are increased speed and decreased capacity of computing resources.

As a result it is possible to simulate both simple and more complex multicellular organisms, collect the data and study their behavior, embryogenesis, self-organization, self-replication, their nervous system, muscular system etc. Of course this will be possible only with the development in this area and a more detailed analysis of the subject area. But it gives significant impetus to future research.

Development in this branch can give important results, which require a lot of time for development and research in both biology and programming. This study presents rather primitive algorithms of the nervous system’s simulation, but further development of hardware enables simulation of much more complex examples and gaining the speed of signal transmission at the level of human neural network.

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