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# Evolution And Particularities Of The Cellular Automata Application. Background To The Use Of Tetralogics And Tetracodes In Cellular Automata

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**ABSTRACT**

The basic directions are determined in the evolution of cellular automata theory. Various areas of knowledge are identified, where cellular automata are used. A detailed analysis is made of the cellular automata use in various fields of scientific knowledge. Premises are designated to use the extended code-logical basis for encoding the states of cellular automata.

**Key words :** Cellular automata, the game «Life», an advanced code-logical basis, post-binary cellular automata, tetralogic, tetracode.

## 1. INTRODUCTION

Cellular automata (CA) are, in fact, simple discrete dynamical systems, which give the ordered structures, arising from random initial conditions. CA is a kind of mathematical idealizations of physical system in which space and time are discrete, and physical quantities take a finite set of values [1]. In this sense, cellular automata in computer science are analogous to the physical concept of «field».

In the last decade such computational problems are increasing and are gaining relevance that requires capacities for their solutions which far exceeding the possibility of personal (single processor) computer. Therefore, it is turned natural the transition to the process of the computing organization in which programs are designed as a set of interacting computational processes running in parallel. This transition has given impulse to the development of multiprocessor architecture, efficient use of computing clusters, as well as the active development of specialized packages for parallel programming interfaces.

Cellular automata form a common paradigm of parallel computing, just as do the Turing machines for sequential computations. Therefore, in the transition to parallel computing, cellular automata can be seen as computers, originally adapted for parallel processing and having wide application in the calculation of complex functions.

The aim of this work is to examine the evolution and the population of the CA, as well as the advantage of the CA implementation in the extended code-logical basis.

## 2. The Main Trends In The Evolution Of the CA Theory

The study of cellular automata has an almost 75-year history, ranging from works on self-reproducing structures (John von Neumann) to contemporary works in various fields of science.

Each cellular automate is represented by a set of four components: a lattice (grid); metrics; data warehouse (datum); rules. The presence of these components allows to create the CA with different features, as well as to distribute development of the experiment system between different performers. If necessary, it can optionally be used fifth component type in CA – analyzers for analysis of quantities characterizing the CA metric (e.g., the coordinate system) [2].

The idea of cellular automata (CA) was firstly proposed in the 40s by German engineer Konrad Zuse and Polish mathematician Stanislaw Ulam, but its practical implementation was carried out by the American mathematician John von Neumann in order to reproduce the behavior of complex spatially extended systems [3]. At the end of the 40s, having accumulated a rich practical experience in the creation of high-speed computers, von Neumann began to establish a mathematical theory of automata, in which the idea was considered of the possibility of constructing a self-replicating machines, i.e. those machines that guided by the appropriate instructions will be able to reproduce an exact copy of themselves [4]. In this work, von Neumann substantiated that many biological processes naturally described in terms of cellular automata, rather than differential equations [5].

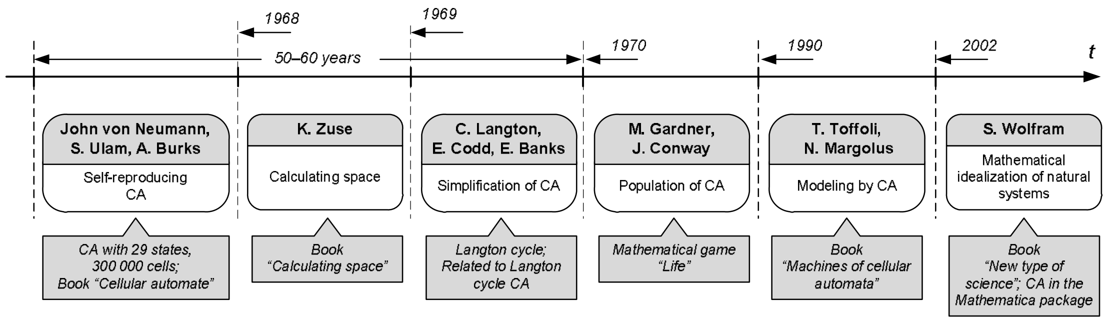


**Figure 1 – The main directions in the evolution of cellular automata theory**

Six main directions can be identified in the development of the CA theory (Fig. 1).

**2.1 Self-replicating automata.**

At the end of the 40s, having accumulated a rich practical experience in the creation of high-speed computers, von Neumann began to establish a general mathematical theory of automata. John von Neumann considered the idea of the possibility of creating self-replicating machines. If such a machine to provide appropriate instructions – it will have to reproduce an exact copy of itself [6].

However, the theory on a possibility of self-replicating machines creation have not been carried out by von Neumann in practice, because the technology of his time did not allow the possibility of practical implementation [7]. Studies were continued after the death of von Neumann by his student Stanislaw Ulam and John Holland – the staff members of the University of Los Alamos at the University of Michigan. They started to design the machine, using the concept of what we today call a cellular automate. The result of the work started in the 50s and completed after the death of von Neumann in 1957 by Arthur Burks was the cell model of self-reproduction, which is a two-dimensional field of cells, each of which is a finite state automate with 29 states, each cell has four neighbors [8–10].

**2.2 The calculating space.**

Almost in parallel and independently of Ulam and von Neumann's research, Konrad Zuse began work on the CA, who in 1969 published a book «Rechnender Raum» – «Calculating Space». In this book, the idea was firstly presented that our Universe is a huge functioning cellular automate. And there are infinitely small particles, the units, by which the Universe «thinks». The concept is introduced of digital particle of calculating space. Particular interest attracted the use of these systems to the problems of numerical modeling in mechanics and physics problems [11].

Digital particles, in the case of neighborhood, interact with each other, causing periodic changes in the whole system. Zuse calls this phenomenon «floating state». That is why digital particles can be considered as the «self-reproducing systems» [12].

**2.3 Simplification of the CA.**

In 1984, Christopher Langton has created self-replicating automate, which cell can be in one of eight possible states, but for self-reproduction it requires far fewer cells than hundreds or thousands of cells necessary for self-reproduction in the Neumann's machine. Thus, Langton refused universal automate, but significantly simplified it.

After Langton, self-reproducing automata theory began to move in the direction of simplification. Among the Langton's followers are widely known works of Edgar Codd (1968), Edwin Roger Banks, H. H. Chou, J. Reggia (1993), Byl (1999) and other researchers, which resulted in the emergence of numerous CA with the number of states from 8 to 64 [9, 13, 14].

The most famous follower who continued research in the field of CA simplification was the English mathematician John Horton Conway – creator of mathematical game «Life».

**2.4 The population of the CA as a mathematical game «Life».**

Firstly, mathematical game "Life" appeared in October 1970 in an article «Mathematical Games» by Martin Gardner's on pages of «Scientific American» issue [7].

The main idea is based on the fact that, starting with a simple configuration of organisms, one in each cell, to observe how it changes when «genetic laws» of birth, death and survival are applied to it. Each cell contains only two states (0 – dead, 1 – live) and eight cells-neighbors, which will affect the subsequent state of the cell. Situations emerging in the game are very similar to the real processes occurring at the birth, development and death of living organisms. Although the game consists of a few simple rules, it had some influence on the further development of many branches of mathematics and informatics: automata theory, algorithm theory, game theory, algebra and number theory, probability theory, fractal geometry, computational mathematics [3].

**2.5 Simulation on cellular automata.**

In 1990, the book «Machines of cellular automata» of American scientists from MIT Tom Toffoli and Norman Margolus was published in translation into Russian (translated from English by P. A. Vlasov, N. V. Baranov, edited by B. V. Batalov) where the main achievements were systematically stated in the field of CA.

**2.6 Mathematical idealization of natural systems.**

Fundamental research in the field of CA was conducted by Stephen Wolfram [1, 15–17]. In 2002 he published a great work «A new type of science». It is an encyclopedia of cellular automata [18].

Wolfram pays great attention to the possibility of using CA in many areas of science, including artificial intelligence, biology, chaos theory, computer science, consciousness, economics, fluid dynamics, space exploration, logic, mathematics, and physics. The general idea is that complicated phenomena can be explained by simple mechanisms. It shows that, for example, simple models based on 2-D CA gave the opportunity to generate by a computer the «snowflakes» identical to natural snowflakes; many species of crustacean shells – only simple variants of a single inartificial «program». Most global idea of the book – the Universe can be represented by a cellular automate [18].

**3. Cellular Automata In Various Fields Of Scientific Knowledge.**

Today, cellular automata are widely used in various fields of scientific knowledge: mathematics, physics, biology, chemistry, sociology, and others. As a result, any such names as «iterative arrays», «homogeneous structures», «calculating spaces» (a term introduced by K. Zuse) – which are synonymous with the term «cellular automata» (a term introduced in the book of A. Burks «Cellular automata»).

«Iterative arrays» is a term, to which mathematicians came, studying iterative transformation of spatially distributed structures with discrete set of states. New theoretical problems began to appear to be addressed, such as issues of reversibility, computability, reachability, adaptation, optimization of iterative arrays and others.

«Homogeneous structures» is a term denoting hardware of the CA implementation, the main feature of this structure – the homogeneity [19].

The range of CA application is extremely wide. Below is a list of areas of science and some of the specific tasks which used cellular automata:

1. Computer engineering and computer science: computer modeling of reconfigurable multistage micro-conveyors; the use of quantum dots for the implementation of the microprocessor; the use of genetic algorithms of evolution in cellular automata; simulation of automata networks; cellular programming approach; the use of CA in the simulation of sequential loops and others.
2. Cryptography: alternative cryptograms on cellular automata and others.
3. Mathematics: a study of various properties of the CA; generation of statistically homogeneous planar graphs, etc.
4. Physics: a study of the laws of thermodynamics and hydrodynamics, fluid dynamics and gas dynamics by simulating in CA; reduction and behavior of quantum particles; modeling of the structure and growth of the crystal; simulation of condensation and non-isothermal gas flows, etc .
5. Chemistry: simulation of a plane-parallel flow of fluid by the CA; modeling of chemical systems; cellular automata and local laws in structural chemistry and others.
6. Ecology: some models of lattice gas class, associated with the description of the population; CA as a paradigm of evolutionary modeling; modeling of the spread of diseases; growth of population; modeling of forest fires and others.
7. Biology: modeling of life and growth of bacteria; modeling of morphogenesis and other processes in biology.
8. Medicine: patterns of self-regulation and human blood circulation; simulation of brain tumor growth with the use of three-dimensional CA and others.
9. Epidemiology: the spread of influenza virus infection and other processes in epidemiology.
10. Geology: modeling changes of the earth's surface by the CA.
11. Architecture: modeling of the growth of the city by the CA.
12. Sociology: modeling the crowd movement; modeling of electoral processes; modeling of information distribution in the society, etc.
13. The theory of neural networks: the study of wave processes in neural networks; neural networks with self-organization in classification problems and image processing based on CA etc.

**4. The Prerequisites For The Cellular Automata Using With An Extended Code Logical Basis**

After analyzing the existing to date hardware and software implementation of cellular automata, the following conclusions can be made:

1. CA is widely used in many fields of knowledge for the study of a variety of complex real-world processes.

2. Problem solving based on cellular automata requires a large amount of memory for storing states of the lattice leads to the implementation of a large number of iterations, which requires significant improvements of CA performance.

3. In order to obtain the greatest benefit from the use of cellular automata in practice, it is necessary to apply the relevant parallel software or hardware.

In the mid-90s there were qualitative changes in the development of logical basis, as well as in the field of computer technology, which led to the relevance of the corresponding changes in code-logic [20] and in algorithmic [21] basis of modern computer technologies, which led to the appearance post-binary computing.

It should be noted that the category post-binary computing can be attributed to many areas of current research, which go beyond the binary logic and binary representation of numerical values. In this paper we consider one of the areas post-binary computing – the concept of a generalized code-logical basis [20, 22–26].

In [27] the author emphasizes some of the factors that influenced the «transition from the predominance of the fixed point certainty in logical, arithmetical and algorithmic fundamentals of computer systems to the evolving multiplicity and uncertainty»:

1) The growing interest in science to the research related to the emergence of new logical systems that are richer than classical in its functionality, such as multi-valued (infinite-valued) and continuum logics, which led to the emergence of a new branch of research – «adaptive logic» under the leadership of D. Battens [28].

2) The transition from abstract logic to practically usable logical systems, which are the basis of computer technology, artificial intelligence and programming [28].

3) The development of computer technology mainly associated with the transition from the predominance of sequential von Neumann's principle of organization of the computational process to parallelism at all levels of the organization of computing structures [27].

In the CA theory the desire also identified to complicate the logic of the machine, as evidenced, for example, the appearance of such type of CA as «colored» cellular automata.

Thus the trends appearance can be noted to increasing the number of possible states of the CA. In relation to the advent and use of the extended code-logical basis [20], the CA states can be overridden in the framework of this concept. This approach involves identifying new types of CA in which the state of automata can be set by post-binary codes.

In relation to the advent of post-binary computing we can talk about a new kind of cellular automata – post-binary cellular automata (PCA). The category of PKA are those kinds of CA, where the number of possible states is greater than 2.

## CONCLUSIONS

Based on a review in this paper the evolution and classification, as well as analysis of the CA theory and ideas of extended code-logical basis the following conclusions can formulated:

1. To date, the CA are widely used in many fields of knowledge for the study of a variety of complex real-world processes.

2. The tendency to increase the number of possible states of the CA, which has led to the emergence of new types of CA, which in this paper are united under a common name – post-binary cellular automata.

3. Problem solving based on cellular automata requires a large amount of memory for storing states of the lattice and leads to the implementation of a large number of iterations, which requires significant improvements of CA performance.

4. To obtain the maximum benefits from the use of CA in practice, it is necessary to apply the relevant parallel software or hardware.

In relation to the above facts, it is necessary to implement the following tasks in the study of the new structure of cellular automata:

extension of algorithmic capabilities of CA through the use of post-binary coding;

improvement of software for the CA by extending their functionality;

development of parallel software implementations of CA based on tetralogic and tetracodes [22–27];

development of structural solutions for high-performance hardware and software implementation of the CA as a network resource.

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