THE MAIN STAGES OF THE CELLULAR AUTOMATA THEORY FORMATION

ОСНОВНЫЕ ЭТАПЫ СТАНОВЛЕНИЯ ТЕОРИИ КЛЕТОЧНЫХ АВТОМАТОВ

***Aladjev V.Z.*[1]**

От редакции. *Аладьев Виктор Захарович, ученый советской школы, волею судьбы оказавшийся после распада СССР за границей России, основоположник русскоязычной терминологии в области клеточных автоматов, автор около 100 монографий и более 600 научных статей. В 1972 г. ему была присвоена докторская степень по математике (Dr.Sc.) Университета Южной Калифорнии (у проф. Р. Беллмана) за работу "Mathematical Theory of Homogeneous Structures and Their Applications". В.З. Аладьев в 1966 г. закончил университет и в 1972 г. аспирантуру в Таллине, где им была создана Эстонская школа по математической теории однородных структур, фундаментальные результаты которой получили международное признание и легли в основу нового раздела современной математической кибернетики.*

Виктор Захарович предложил опубликовать у нас одну из глав своей готовящейся монографии, где дал свое видение этапов развития теории клеточных автоматов с учетом важных исторических моментов и значительной роли отечественных исследователей.

Abstract. *Paper presents our standpoint on the main stages of the cellular automata theory formation, based on our many years of research in this field. Along with English-speaking authors, the results of Soviet and Russian authors are presented, who made a fairly significant contribution to the theory of cellular automata, emphasizing a rather essential contribution of domestic researchers in this direction. Finally, our standpoint is presented on the place of the problematics of cellular automata in the system of modern natural science.*

Keywords: *cellular automata, homogeneous structures, modelling, parallel processing, reversibility, automata theory, computing models.*

DOI: 10.21681/2311-3456-2022-1-10-17

Presently, the cellular automata theory is a fairly independent component of the general automata theory, substantially, having an interdisciplinary character with numerous applied aspects in a fairly wide range of fields. Today, the scope of applications of *cellular automata* (***CA***), for all their commonality, is quite extensive and requires special consideration which goes beyond the scope of this article. At present, the ***CA***–concept, along with an independent interest with different degrees of intensity, is used as an important object of research in a wide enough range of applications, namely: cybernetics and physics, computational theory, applied and pure mathematics, synergetic, pattern recognition and signal processing, urban studies, coding theory, theoretical and mathematical biology, computer science, cryptography, mathematical and physical modelling, geology, information processing, etc. Moreover, different ***CA***–objects can quite successfully model the most common phenomenological aspects of real world along with direct physical laws and processes at the microscopic level. ***CA***–models represent a certain kind of formal *recursive* worlds, while recursion itself is one of the fundamental concepts in mathematics, physics, computer science, biology, medicine, linguistics and even in art. For this reason, for today such models are in great demand, attracting an increasing number of researchers from a wide variety of fields of natural and social sciences. However, the above situation has developed, mainly, in recent years, having gone more than half a century, at the beginning of which there were a handful of researchers inspired by works of pioneers in this field such as *Konrad Zuse, S. Ulam* and *John Von Neuman*.

The beginning of cellular automata dates back to the so–called *classical cellular automata* (***CA, CA***–*models*), the definition of which, without overloading the presentation, can be found, in particular, on Wikipedia *(concept of "classical cellular automata" can be found in detail in* [4-9]). Further development led to the emergence of various modifications and types of cellular automata *(polygenic, non–deterministic, stochastic and others, including quantum cellular automata that refers to some models of quantum computation, which have been devised in analogy to known conventional models of cellular automata. It may also refer to quantum dot cellular*

1 Victor Z. Aladjev, Dr.Sc. (Math.), Professor, International Academy of Noosphere, Tallinn Research Group, Tallinn, Estonia. E-mail: aladjev@europe.com

automata, which is a proposed physical implementation of "classical" ***CA*** *by exploiting quantum mechanical phenomena)*. We will present below our standpoint on the brief historical survey of *classical cellular automata* theory as a conceptual basis of all modifications and types of cellular automata, given our research on the problematic in the early steps of its formation as a separate direction. However, despite this, our point of view on the main stages of the formation of classical cellular automata theory can be subjective to a certain extent.

Our interest in ***CA*** issues arose as a result of acquaintance in Leningrad *(now St. Petersburg)* in *1969* with the Russian translation of the excellent collection [1], containing articles by *E.F. Moore, S. Ulam* and *J. Mayhill*, which stimulated our research on ***CA***–problematics. As a result of these studies, at the end of *1970* an informal group of researchers from certain scientific centres was formed, hereinafter referred to as *Tallinn Research Group (**TRG**)*, the defining focus of which was homogeneous structures *(cellular automata)* and their applications. The first results in this field were presented in the monograph [2], which was one of the first works on ***CA***–problematic in the *USSR*. This monograph contained Russian terminology and a number of early results of the ***TRG*** in ***CA*** problematic of both theoretical and certain applied character *(above all,* ***CA****-approach for biological modelling)*. In annual meeting of the Estonian Academy of Sciences this monograph was marked as one of the better works of the Academy for *1972*. In order not to clutter the statement, we simply give references to the main ***TRG*** works [3-10], that in turn contain numerous useful references to related works.

Today, the problematic of cellular automata *(**CA, CA**–models)* is rather well advanced, being quite independent direction of the mathematical cybernetics, having own terminology and axiomatic at the existence of broad enough domain of various appendices. In addition, it is necessary to note that at assimilation of this problematics in the *USSR* in Russian–lingual terminology, whose basis for the first time have been laid by us at *1972* [2] for the concept *«Cellular automata»*, the term *«Homogeneous structures» (**HS; HS**–models)* has been determined which nowadays is the generally accepted term together with a number of other our notions, definitions and denotations [2,4]. Whereas rather detailed list of various publications on ***CA***–problematic can be found, for example, here [2–10]. Therefore, during the present survey along with this term its well–known Russian–lingual equivalent *«Homogeneous structures»* can be used too.

*Cellular automaton (**CA**)* – a parallel information processing system which consists of infinity intercommunicating identical finite *Mealy* automata *(an elementary automaton)*. We can interpret ***CA***s also as a theoretical basis of artificial high parallel information processing systems. From logical point of view a ***CA*** is an infinite automaton with specific internal structure. Thus, the ***CA*** theory can be considered as structural and dynamical theory of the infinite automata. In addition, ***CA*** models can serve as an excellent basis for modeling of many discrete processes, representing interesting enough independent objects for researches too. Recently, the undoubted interest to the ***CA***-problematics *(above all in the applied aspect)* has arisen anew, and in this direction many remarkable results have been obtained. Further, by the ***CA*** we mean both cellular automata and a separate cellular automaton, depending on the context.

Thus, the ***CA***–axiomatic provides three fundamental properties such as *homogeneity*, *localness* and *parallelism* of functioning. If in such similar computing model we shall with each elementary automaton associate a separate microprocessor then it is possible to unrestrictedly increase the size of similar computing system without any essential increase of its temporal and constructive expenses, required for each new expansion of this computing space, and also without any overheads connected to the coordination of functioning of any supplementary quantity of elementary microprocessors. Similar high–parallel computing models admit practical implementations consisting of large enough number of rather elementary microprocessors which are limited not so much by certain architectural reasons as by a lot of especially economic and technologic reasons that are determined by the modern level of development of microelectronic technology, however with the great potentialities in the future, first of all, in light of rather intensive works in field of nanotechnology. In addition, ***CA*** models can be used rather successfully for the problems solving of information transformation such as image processing, data compression, encryption, encoding, and many others [10].

The above three such features as high homogeneity, high parallelism and locality of interactions are provided by the ***CA***–axiomatic itself, whereas such property important from the physical standpoint as reversibility of dynamics is given by program way. In light of the listed properties even classical ***CA*** are high–abstract models of the real physical world, which function in a space and time. Therefore, they in many respects better than many others formal architectures can be mapped onto a number of physic realities in their modern understanding. Moreover the ***CA***–concept itself is enough well adapted to solution of different problems of modelling in areas such as mathematics, cybernetics, development biology, theoretical physics, computing science, discrete synergetic, dynamic systems theory, robotics, etc. Numerous visual examples available for today lead us to a conclusion that ***CA*** can represent a rather serious interest as a new rather perspective environment of modelling and research of different discrete processes and phenomena, determined by the above properties; at that, by bringing the ***CA***–problematic on a new interdisciplinary level and, on the other hand, as a rather interesting independent formal mathematical object of researches [5-9].

The base modern tendencies of elaboration of perspective architecture of high parallel computer facilities, the problem of modelling of the discrete parallel processes, discrete mathematics and synergetic, theory of parallel discrete dynamical systems, problems of arti-

DOI:10.21681/2311-3456-2022-1-10-17

ficial intellect and robotics, parallel information processing and algorithms, physical and biological modeling, along with a lot of other important prerequisites in the different areas of modern natural sciences define at the latest years a new ascent of the interest to the formal cellular models of different type which possess a high parallel manner of acting; the cellular automata are certain of major models of such type. During time which has passed after appearance of the first monographs and the collected papers that have been devoted to various theoretic and applied aspects of the ***CA***–problematic, the certain progress has been reached in this direction, that is connected, above all, with successes of theoretical character along with essential expansion of field of different appendices of the ***CA*** models, especially, in computer science, cybernetics, physics, modelling, developmental biology with substantial growth of a lot of researchers in this direction. At the same time in the USA, Germany, the Great Britain, Japan, Hungary, Estonia, etc., a lot of works summarizing the results of progress in those or other directions of the ***CA***–problematic including its numerous appendices in various fields has appeared. So, our monographs and reports at a certain substantial level have represented the reviews of the basic results which have been received by the ***TRG*** on ***CA***–problematic and its applications [3-10]. From the very outset of our researches on the ***CA***–problematic, first of all, with an application accent onto mathematical developmental biology the informal ***TRG*** consisting of researchers of certain scientific centres of the former *USSR* has gradually been formed up. At that, the ***TRG*** staff was not strictly permanent and was being changed in rather broad bounds depending on the studied problems. In works [3-10] the analysis of the ***TRG*** activity instructive to some degree for research of the dynamics of development of the ***CA***–problematic as a independent scientific direction as a whole had been represented. Ibidem, our basic directions of study can be found along with main received results.

Today, cellular automata are being investigated from many standpoints and interrelations of the objects of such type along with already existing problems are being discovered constantly. For general acquaintance with extensive ***CA***–problematic as a whole along with its separate determining directions specifically, we recommend to address oneself to interesting and versatile reviews of the researchers such as *V. Cimagalli, V. Aladjev, K. Culik, D. Hiebeler, A. Lindenmayer, A.R. Smith, P. Sarkar, T. Toffoli, M. Mitchell, R. Vollmar, S. Wolfram*, et al. [10]. A number of books and monographs of the authors such as *V.Z. Aladjev, T. Toffoli, R. Vollmar, A. Adamatzky, V. Kudrjvcev*, *M. Sipper, A. Ilachinskii, M. Garzon, P. Kendall, B. Voorhees, O. Martin, K. Preston, S. Wolfram, E. Codd, N. Margolus, B. Voorhees,* along with certain others contain an interesting enough historical excursus in ***CA***-problematic; in addition, unfortunately, hitherto a common standpoint onto historical aspect in this question is absent. In view of that, here is a rather opportune possibility to briefly emphasize *(taking into account our familiarity with the issue at an early stage of its origin)* once again our standpoint on a historical aspect of ***CA***–problematic: the brief historical excursus presented below make it one's aim to define the basic stages of becoming of the ***CA***–problematic *(primarily classical cellular automata)*, having digressed from numerous particulars.

Having started own study on the ***CA***–problematic in *1969*, we on base of analysis of large number of publications and direct dialogue with many leading researchers *(S. Amoroso, A. Burks, H. Yamada, R. Vollmar, E.F. Codd, A. Adamatzky, T. Toffoli and others)* in this direction, we have a quite certain information that concerns the objective development of its basic directions, first of all, of theoretical character. That allows us with quite sufficient degree of objectivity to highlight the pivotal stages of its development; at the same time, numerous details of historical character concerning the ***CA***–problematic the reader can find, for example, in a lot of works presented in links [3,10].

From theoretical standpoint the ***CA*** concept has been introduced at the end of the forties of the past century by *John von Neumann* on *S. Ulam*'s advice with purpose of definition of more realistic and well formalized model for study of behaviour of complex evolutionary systems, including self–reproduction of the alive organisms. Whereas *S. Ulam* has used ***CA***–like models, in particular, for research of the growth problem of crystals and some other discrete systems that grows in conformity with recurrent rules. Structures that have been investigated by him and his colleagues were, mainly, of dimensionality *1* and *2*, however higher dimensions have been considered too. At that, questions of universal computability along with certain other theoretical questions of behaviour of cellular structures of such type also were kept in view. A little bit later also *A. Church* started to study the similar structures in connection with works in field of infinite abstract automata and mathematical logic. *J. Neumann*'s ***CA***–model has received further development in works of a number of ofhim direct followers whose results along with the finished and edited work of the first one have been published by *A.W. Burks* in his excellent works [10], that in many respects have defined development of research in this direction for several subsequent years. In process of researches on the ***CA***–problematic *A.W. Burks* has organized at the Michigan university the research team *«The Logic of Computer Group»* from which a lot of the first–class experts on the ***CA***–problematic has come out afterwards *(J. Holland, R. Laing, T. Toffoli, and many others)*.

At the same time, considering historical aspect of the ***CA***–problematic, we should not forget an important contribution to this problematic which was made by pioneer works *Konrad Zuse (Germany)* and with which the world scientific community has been familiarized enough late and even frequently without his mention in this historical aspect. At that, *K. Zuse* not only has created the first programmable computers *(1935–1941)*, has invented the first high–level programming language *(1945)*, but was also the first who has introduced idea of *«Rechnender Raum» (Computable Spaces)*, or in the modern terminology – *cellular automata*. Furthermore, *Konrad Zuse* has supposed that physical processes in point of fact are calculations, while our universe is a certain *«Cellular Automaton»* [10]. In the late seventies of the last century such view on the Universe was innovative, whereas now such idea of the computing Universe horrify nobody, finding logical place in the modern theories of some researchers which work in the field of quantum mechanics [10]. Unfortunately, even at present the *Konrad Zuse*'s ideas in many ways are unfamiliar to rather meticulous researchers in this field. So, for exclusion of any speculative historical aspects existing occasionally today, in the following historical study it is necessary to pay the most steadfast attention on this a rather essential circumstance. So, namely therefore, only many years later the similar ideas have been republished, popularized and redeveloped in the research of other researchers such as *S. Wolfram, T. Toffoli, E. Fredkin*, et al. At that, the ***CA*** concept itself has been entered by *John Neumann*. Perhaps, *John Neumann*, being familiar with *K. Zuse* ideas, could use ***CA*** not only for simulation of process of reproducing automata, but also for building of high parallel computing model in addition *(or instead of)* to his well–known sequential computing model.

From more practical standpoint and game experiment the ***CA*** models has notified about itself in the late *sixties* of the last century when *J. Conway* has presented the now known game *«Life»*. This game became a rather popular and has attracted attention to cellular automata of both numerous scientists from different fields and amateurs [10]. At the same time, this game, probably, is the most known ***CA*** model; at that, it will possess the ability to self–reproduction and universal computing. By modelling the process of work of an arbitrary *Turing* machine by means of a ***CA*** model, *J.H. Conway* has proved ability of the model to universal computability. Later a rather simple manner of implementation of any Boolean function in configurations of the *«Life»* has been suggested [10]. So, even such simple ***CA*** model turned out equivalent to the universal *Turing* machine. Indeed, to the given ***CA*** model the significant interest exists and till now does not disappear above all to its various computer simulating [10]. So, early ideas and study of the first–rate mathematicians and cyberneticians such as *K. Zuse, John von Neumann, S. Ulam, A. Church* along with their certain direct followers we with good reason can ascribe to the ***first*** stage of formation of the ***CA***–problematics as a whole.

The necessity for a good formalized media for modelling of processes of biological development and above all of self–reproduction process was being as one of the base prerequisites which stimulated the ***CA***–concept beginning. At that, *J. Neumann* and a whole series of his direct followers have investigated a series of questions of computational and constructive opportunities of the first ***CA***–models. The above works at the end of the *fifties* of the last century have attracted to the given problematics a quite number of known researchers [10]. At the same time, cellular automata were being rediscovered not once and under various names: in biological sciences as cellular structures, in electrical engineering they are known as iterative networks, while in pure mathematics as a section of topological dynamics, etc. Whereas in any case their conceptual basis remained the same cellular automata.

As ***second*** stage in formation of the ***CA***–problematics it is quite possible to consider publication of the widely known works of *E.F. Moore* and *John Myhill* on the nonconstructability problem in classical ***CA***–models which along with solution of certain mathematical problems in a certain sense became serious accelerators of activity attracting a quite steadfast attention to this problematics of a lot of mathematicians and researchers from other fields [10]. As already noted, we have familiarized oneself with ***CA***–problematics in *1969* owing to Russian translation of excellent work edited by Prof. *R. Bellman*, that contained well–known articles of *E.F. Moore, S. Ulam* and *J. Myhill* [1]. Soon, scientific groups on the ***CA***–problematics in the *USA, Germany, Japan, Hungary, Italy, France*, and *USSR (ESSR, TRG, 1969)* are formed up. The further development and popularization of the ***CA***–problematics can be connected with names of researchers such as *E. Codd, S. Cole, E. Moore, J. Myhill, H. Yamada, S. Amoroso, E. Banks, J. Buttler, V.Z. Aladjev, T. Yaku, J. Holland, G.T. Herman, A.R. Smith, A. Maruoka, Y. Kobuchi, T. Ostrand, G. Hedlund, M. Kimura, A. Waksman, H. Nishio*, and a number of others researchers whose works in the *sixties* – the *seventies* of the last century quite have attracted attention to this problematics from the theoretical standpoint; they have solved and formulated a lot of rather interesting problems [10]. In the future, mathematicians, physicists, and biologists began to use the ***CA*** with the purpose of study of own specific problems. In particular, in the *early sixties* – the *late seventies* of the last century quite numerous researchers have prepared entry of ***CA***–problematics to the current stage of its development that is characterized by join of earlier disconnected ideas, approaches and methods on the general conceptual platform, that is based precisely on *classical* cellular automata concept, along with an essential enough expansion of fields of its application.

We can attribute the beginning of the third period to the early *eighties* of the last century when to ***CA***–problematics the special interest again has been renewed in connection with active enough researches on problem of artificial intellect, physical modelling, elaboration of a rather perspective architecture of high–parallel computer systems, and a number of rather important motivations. So, in our opinion namely since the works of the researchers such as *Bennet C., Grassberger P., Boghosian B., Gács P., Chopard B., Crutchfield J., Culik K., Green D., Gutowitz H., Langton C., Martin O., Ibarra O., Kobuchi Y., Margolus M., Mazoyer J., Toffoli T., Wolfram S., Aladjev V.Z., Bandman O.L.*, etc. a new splash of interest to the ***CA*** began as a rather perspective environment, first of all, of physical modeling. A rather extensive selection of references, including references

DOI:10.21681/2311-3456-2022-1-10-17

on the Soviet and the Russian–language authors, can be found in [9,10]. Thus, at present, ***CA***–problematics are being rather widely studied from extremely various standpoints and interrelations of similar homogeneous structures with rather many existing problems are constantly sought and discovered. A number of large teams of researchers in many countries and, first of all, in Germany, the USA, the Great Britain, Italy, France, Japan, Australia, Russia deals with this problematics. Scientific activity in this direction was carried out and in the Estonia within of the ***TRG,*** whose a whole series of results has received an international recognition and composed a rather essential part of the modern ***CA***–problematics.

The modern standpoint on the ***CA*** (***HS***) theory has been formed under the influence of works of researchers such as *Adamatzky A.I., Aladjev V.Z., Amoroso S., Arbib M., Bagnoli F., Bandini S., Bandman O.L., Bays C., Banks E.R., Barca D., Barzdin J., Binder P., Boghosian B., Burks A. W., Butler J., Cattaneo G., Chate H., Chowdhury D., Church A., Codd E.F., Crutchfield J.P., Culik K.II, Das A.K., Durand B., Durret R., Fokas A.S., Fredkin E., Gács P., Gardner M., Gerhardt M., Griffeath D., Golze U., Grassberger P., Green D., Gutowitz H.A,, Hedlund G., Honda N., Cole S., Hemmerling A., Holland J., Ibarra O.H., Ikaunieks E., Ilachinskii A., Jen E., Kaneko K., Kari J., Kimura M., Kobuchi Y., Langton C., Legendi T., Lieblein E., Lindenmayer A., Maneville P., Margolus N., Martin O., Maruoka A., Mazoyer J., Mitchell M., Moore E.F., Morita K., Myhill J., Nasu M., Neumann J., Nishio H., Ostrand T., Pedersen J., Podkolzin A., Sato T., Richardson D., Sarkar P., Shereshevsky M., Sipper M., Smith A. Sutner K., Takahashi H., Thatcher J., Toffoli T., Toom A., Tseitlin G.E., Varshavsky V.I., Vichniac G., Vollmar R., Voorhees B., Wuensche A.A., Waksman A., Weimar J., Willson S., Wolfram S., Yaku T.* along with other numerous researchers from many countries.

Along with our works in the ***CA*** problematics, it is necessary to note a lot of Soviet researchers who have received in this direction the fundamental and considerable results at the *sixties* – the *eighties* of the last century. Here they: Adamatzky A.I. *(identification of CA–models)*, Bandman O.L. *(asynchronous CA)*, Blishun A., Bliumin S. *(growth of patterns)*, Bolotov A. *(simulation among classes of CA)*, Varshavsky V.I. *(synchronization of CA, simulation of anisotropic CA on isotropic ones)*, Georgadze A.G., Mandzhgaladze P., Matevosian A. *(growth of finite configurations; CA models and parallel grammars, universal stochastic and deterministic CA)*, Dobrushin R., Vasil'ev N., Stavskaya O., Mitiushin L., Leontovich A., Toom A. *(probabilistic CA)*, Kolotov A.T. *(the models of excitable media)*, Podkolzin A.S. *(simulation of CA; asymptotic of global dynamic; universal CA)*, Ikaunieks E. *(nonconstructible configurations)*, Koganov A.V. *(universal CA, simulation of CA, the stable configurations)*, Revin O. *(simulation of anisotropic CA on isotropic CA–models)*, Levenshtein V. *(synchronization in CA)*, Kurdiumov G. and Levin L. *(stochastic CA)*, Makarevskii A.I. *(implementation of Boolean functions in CA)*, Petrov E. *(synchronization of 2D–CA)*, Pospelov D. *(homogeneous structures and distributed AI in CA–models)*, Evreinov E.V., Prangishvili I. *(CA–like architecture of high–parallel processors)*, Reshod'ko L. *(CA of excitable media)*, Solntzev S. *(growth of patterns)*, Tzeitlin G. *(algebras of shift registers)*, Tzetlin M. *(collectives of automata, games in CA–models)*, Scherbakov E.S. *(universal algebras of parallel substitutions)*, and a lot of others researchers.

It is supposed that the ***CA***–models can play extremely important part as both conceptual and the applied models of spatially–distributed dynamic systems among which first of all an especial interest the computational, physical and biological cellular systems present. In this direction already takes place a rather essential activity of a lot of the researchers who have received quite encouraging results [10]. At last, theoretical results of the above-mentioned and of a whole series of other researchers have initiated the modern mathematical ***CA*** theory evolved to the current time into an independent branch of the abstract automata theory that have numerous interesting appendices in various areas of science and technique, in such fields as physics, developmental biology, parallel information processing, creation of perspective architecture of high–efficiency computer systems, computing sciences and informatics, which are linked to mathematical and computer modeling, etc., and by substantially raising the ***CA*** concept onto a new interdisciplinary level. Our concise enough standpoint on the main stages of development and formation of ***CA*** theory is given above; for today there is a number of the reviews devoted to this question, for example [9], many works on the ***CA***–problematics in varying degree also concern this question [10]. At that, it should be noted that the matter to a certain extent has a rather subjective character and that needs to be meant. Moreover, our consideration concerned *classical* cellular automata and although they form the conceptual basis of the cellular automata theory in general, at present this direction has so expanded the problematics of its study, primarily of applied nature, that our review can`t be considered exhaustive in any way, assuming other researches in this direction.

Meanwhile, some researchers in a gust of certain euphoria try to present the ***CA***–approach as a universal remedy of the solution of all problems and knowledge of outward things, identifying it with a *«New Kind»* of science of universal character. In this connection it is necessary to mark the vast and pretentious book of *S. Wolfram* [11], whose title has rather advertising and commercial, than scientific–based character. This book contains many results that have been obtained much earlier by a lot of other researches on ***CA***–problematics, including the Soviet authors *(see references in* [2-9] *and some others)*. In addition, the priority of many fundamental results in this direction belongs to other researchers. The unhealthy vanity of the author of the book does not allow him to look without bias on history of the ***CA***–problematics as a whole. Generally speaking, *S. Wolfram* enough frivolously addresses with authorship of the results that were received in ***CA***–problematics, therefore, there can be an impression – everything made in this field belongs basically to him. At that, the book contains basically results of computer modelling with rather simple types of ***CA***–models, drawing the conclusions and many assumptions on their basis with a rather doubtful reliability and quality. In the book we can meet an irritating density of passages in which the author takes personal credit for ideas which are *«common knowledge»* among experts in the relevant fields. Seems, such *S. Wolfram* passages and inferences very similar to them cause utterly certain doubts in the judiciousness and scientific decency of their author.

At last, we absolutely do not agree that *S. Wolfram* book presents a *"New Kind"* of science; at the same time, the book would be more pleasant to read if it were more modest. In our opinion, *S. Wolfram* book presents in many respects a speculative sight both on ***CA***–problematics, and on the science as a whole. Here we only shall note, that contrary to the pursued purposes the book not only was not revelation for the researches working in the ***CA***–problematics but also to a certain extent has caused a little bit deformed representation about the study domain that is rather perspective from many standpoints. With relatively detailed standpoint that concerns the above book, the reader can familiarize in works [10] and some others. Meanwhile, in spite of the told above relative to the book, it can present a certain interest, taking into consideration the marked and other remarks. In our opinion, the *S. Wolfram* bulky book doesn't introduce of anything essentially new in the ***CA*** theory, firstly, in its mathematical component.

Now, we will make one essential enough remark concerning of the place of the ***CA***–problematics in scientific structure. By synchronization with the standpoint on the ***CA***–problematics that is declared by our book [6] a vision of the given question is being presented as follows. Our long–term experience of investigations in the ***CA***–problematics both on theoretical and especially applied level speaks entirely about another, namely:

*(**1**) **CA**–models (cellular automata, homogeneous structures) represent a special class of infinite abstract automata with specific internal structure that provides extremely high–parallel level of the information processing and calculations; these models form a specific class of discrete dynamic systems which function in especially parallel way on base of principle of local short–range interaction;*

*(**2**) **CA** can serve as a satisfactory model of high–parallel processing just as Turing machine (Markov normal algorithms, productions systems, Post machine, etc.) serve as formal models of sequential calculations; from this standpoint the **CA**–models it is possible to consider and as algebraic processing systems of finite or infinite words, defined in finite alphabets, on the basis of a finite set of rules of parallel substitutions; in particular, **CA**–model can be interpreted as a certain system of parallel programming where the rules of parallel substitutions act as a parallel language of the lowest level;*

*(**3**) the principle of local interaction of elementary automata composing a **CA**–model that in result defines their global dynamics allows to use the **CA** and as a fine environment of modelling of a broad enough range of objects, processes and phenomena; in addition, the phenomenon of the reversibility permitted by the **CA** does their by interesting enough means for physical modelling, and for creation of rather perspective computing structures that base on the nano– and quantum–technologies;*

*(**4**) **CA**–models represent a rather interesting independent mathematical object whose essence consists in high–parallel processing of words both in finite and infinite alphabets*.

At that, it is possible to associate the ***CA***–approach with a certain model analogue of the differential equations in partial derivatives that describe those or another processes onlly with that difference, that if differential equations describe a process at the average, in a ***CA***–model determined in appropriate way, a certain researched process is really embedded and dynamics of the ***CA***–model enough evidently represents the qualitative behaviour of studied process. Thus, it is necessary to determine for an elementary automaton of the model the necessary properties and rules of their local interaction by an appropriate way. The ***CA***–approach can be used for study of processes described by complex differential equations which have not of analytical solution, and for the processes that can`t be described by such equations. Moreover, the ***CA*** represent a perspective modelling environment for research of those phenomena, processes, and objects for which there are no known classical means or they are rather complex. The experience of applying ***CA***–models in in this term clearly showed their promise for such purposes.

As we already noted, as against many other modern fields of science, the theoretical part of the ***CA***–problematics is no so appreciably crossed with its second applied component, therefore we can consider ***CA***-problematic as two independent enough directions: study ***CA*** as mathematical objects and use ***CA*** for modelling; at that, the second direction is characterized even by essentially wider spectrum. The level of evolution of the second direction is appreciably being determined by possibilities of the modern computing systems because ***CA***–models, as a rule, are being designed on base of the immense number of elementary automata, having, as a rule, rather complex rules of local interaction among themselves.

The indubitable interest to them amplifies also a possibility of practical realization of high parallel computing ***CA*** on basis of modern successes of microelectronics and future prospects of information processing at the molecular level *(methods of nanotechnology);* whereas the ***CA***–concept itself provides creation of conceptual and practical models of various spatially–distributed dynamic systems of which physical systems are the most interesting and perspective. Indeed, models which in obvious way reduce certain macroscopic processes to rigorously defined microscopic processes represent special epistemological and methodical interest for they possess the great enough persuasiveness and transparency. Namely, of this standpoint the ***CA***–models of

DOI:10.21681/2311-3456-2022-1-10-17

different type represent an especial interest, above all, from the applied standpoint at study of a lot of objects, phenomena and processes in various fields, first of all, in developmental biology, physics and computer science.

If the first direction enough intensively is developed by mathematicians than contribution to development of the second direction quite essentially more representative circle of researchers from different theoretical and applied fields *(physics, chemistry, biology, technique, etc.)* brings. So, if theoretical study on ***CA***–problematics in general are limited to polygenic, classical and stochastic ***CA***–models, then results of the second direction base on quite essentially wider representation of classes and types of the ***CA***–models. As a whole, if classical ***CA***–models represent first of all the formal mathematical systems studied in appropriate context, then their numerous generalizations represent a rather perspective environment of modelling of various objects.

In the conclusion once again it is necessary to note an important enough circumstance, at discussion of the *Classical cellular automata (CCA)* we emphasized the following an essential enough moment. We considered ***CCA***–models which are a class of parallel discrete dynamic systems as certain formal algebraic systems of processing of finite configurations *(words)* in finite alphabets whatever, as a rule, to their microprogrammed environment, i.e. without use of their cellular organization on the lowest level inherent into them, what distinguishes our approach to research of the given objects from approaches of a number of other researchers. Also we consider ***CCA***–model as a formal mathematical object having specific inside organization without ascribing to them a certain universality and generality in perception of the Universe. At such approach the ***CCA*** are considered at especially formal level not allowing using to the full their intrinsic property of extremely high parallelism in field of computations and information processing as a whole.

Naturally, for solution of a number of various applied problems in the ***CA***–environment and obtaining of a series of thin results, first of all, of model character an approach on microprogram level is needed when a researched process, algorithm or phenomenon is directly embedded in a ***CA***–model, using its parameters: *dimensionality, neighbourhood index, a states alphabet and a local transition function*. At such approach we can obtain solutions of a lot of important appendices with generalizations of a rather high level of theoretical character. Particularly, direct embedding of universal computing algorithms or logical elements into such objects allows to constructively prove existence of the universal computability, etc. In spite of such extremely simple concept of the ***CCA,*** they by and large have a rather complex dynamics. In many cases theoretical research of their dynamics collides with a rather complexity. Therefore, computer simulation of these structures which in empirical way allows to research their dynamics is a rather powerful tool. For this reason this question is a quite natural for investigations of the ***CA***–problematics, considering the fact that ***CA***–models at the formal level represent the dynamic systems of high–parallel substitutions.

Indeed, the problem of computer modelling of ***CA*** is solved at two main levels: *modelling of* ***CA*** *dynamics on computers of traditional sequential architecture and modelling on hardware architecture that corresponds to the maximal possible to* ***CA*** *concept; so-called* ***CA***–*oriented architecture of computer systems*. So, computer simulation of the ***CA***–models plays a rather essential part at theoretical research of their dynamics; meanwhile, it is even more important at practical realizations of the ***CA***–models of different processes. At present, a whole series of interesting systems of software and hardware for help of investigations of different types of the ***CA***–models have been developed; their characteristics can be found in the references [10]. In our works a lot of programs in various program systems for different computer platforms had been presented. Among them a number of rather interesting programs for simulation of the ***CA***– models in the *Mathematica* and *Maple* systems has been programmed. On the basis of computer simulation a number of interesting theoretical results on the ***CCA*** and their use in such fields as developmental biology, mathematics, computer sciences, etc. had been received. However, the given matter along with applied aspects of the ***CA***–models in the present article aren`t considered, despatching the interested reader to a rather detailed discussion of these aspects to the corresponding publications in lists of references [10] and in references given in [6-9]; it is a lot of rather interesting works can be found in Internet by the appropriate key phrases.

The problematic considered by the ***TRG*** study in many respects has been conditioned by interests and tastes of the authors along with traditions of creative activity of the ***TRG*** in this field. In addition, we will note that in our activity it is possible to allocate three main directions: *(**1**) research of classical* ***CA*** *as a formal parallel algorithm of configurations processing in finite alphabets*, *(**2**) applications of classical and generalized* ***CA*** *in mathematics and computer facilities of highly parallel action, including (**3**) mathematical and developmental biology*. The interested reader can familiarize in sufficient detail with our results in this directions in [2-9] and in numerous references contained in them along with references that concern many other researchers in this field.

References

1. Mathematical Problems in Biology / Ed. R. Bellman.– New–York: Academic Press, 1962.
2. V.Z. Aladjev. To the Theory of the Homogeneous Structures.– Tallinn: Estonian Academic Press, 1972 (in Russian).
3. Links https://files.portalus.ru/dl/files/Our_publications_2019.pdf and https://files.portalus.ru/dl/files/TRG.html
4. V.Z. Aladjev. Mathematical theory of homogeneous structures and their applications.– Tallinn: Valgus Press, 1980, 270 p.
5. V.Z. Aladjev. Homogeneous Structures: Theoretical and Applied Aspects.– Kiev: Technika Press, 1990 (in Russian).
6. V.Z. Aladjev. Classical homogeneous structures: Cellular Automata.– USA: Palo Alto: Fultus Books, 2009, 535 p., ISBN 159682137X
7. V.Z. Aladjev. Classical Cellular Automata: Mathematical Theory and Applications.– Germany: Saarbrucken: Scholar`s Press, 2014, 512 p.
8. V.Z. Aladjev, M.L. Shishakov, V.A. Vaganov. Selected problems in the theory of classical cellular automata.– USA: Lulu Press, 2018, 410 p.
9. В.З. Аладьев, В.А. Ваганов, М.Л. Шишаков. Базовые элементы теории клеточных автоматов.– USA: Lulu Press, 2019, 418 с.
10. Links on the CA–problematics – http://www.hs-ca.narod.ru, or http://ca-hs.weebly.com
11. S. Wolfram. A New Kind of Science.– N.Y.: Wolfram Media, 2002.
12. Interview on the CA problematics – https://all-andorra.com/ru/viktor-aladev-o-bazovyx-elementax-odnorodnyx-struktur-i-teorii-kletochnyx-avtomatov (in Russian)

DOI:10.21681/2311-3456-2022-1-10-17