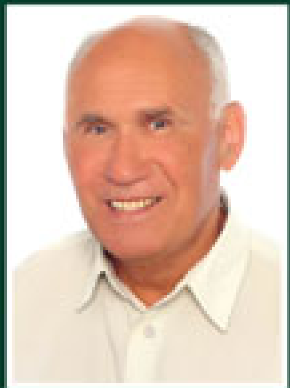

Professor Aladjev V. was born on June 14, 1942 in the town Grodno (Byelorussia). Now, he is the First vice-president of the International Academy of Noosphere and academician-secretary of Baltic branch of the Academy whose scientific results have received international recognition, first, in the field of the theory of Cellular Automata. Aladjev V. is known for the works on mathematical software. He is full number of Russian and International Academies. Aladjev V. is the author of more than 420 scientific publications, including 72 books, published in many countries. He participates as a member of the organizing committee and/or a guest lecturer in many international scientific forums in mathematics and cybernetics.

In the monograph we present some results of the work we have done in the theory of classical Cellular Automata (CA) during 1969-2010, in truth with considerable enough pauses. These results form the essential enough part of the CA-problematics. In particular, we have considered such problems as the nonconstructability problem, decomposition of global transition functions, extremal constructive opportunities, complexity of finite configurations and global functions, parallel formal grammars and languages defined by CA, the modelling problem in classical CA, the certain applied aspects of CA, etc. At present, the CA-problematics is the well enough developed independent sphere of the modern mathematical cybernetics which has considerable field of numerous appendices.

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V.Z. Aladjev · Classical Cellular Automata. Homogeneous Structures

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Classical Cellular Automata

Homogeneous Structures

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Table of Contents

List of the adopted abbreviations and designations

∞–MEC – infinite mutually–erasable configurations
AI – Artificial Intelligence
APS – algorithms of parallel substitutions
AS – an algebraic system
C(A,d,ϕ) – a set of finite ***d***–dimensional configurations defined in a state alphabet ***A***
C(A,d,∞) – a set of infinite ***d***–dimensional configurations defined in a state alphabet ***A***
CA – cellular automata ***(CA–models)***
CAS – computer algebra system
CF – configuration(s); depending on context
CHCS – concentrated homogeneous computing systems
d–GDP – ***d***–dimensional global decomposition problem ***(d ≥ 1)***
d–GLDP – ***d***–dimensional generalized global decomposition problem ***(d ≥ 1)***
d–HS – ***d***–dimensional homogeneous structure(s) ***(d ≥ 1)***
d–HSR – ***d***–dimensional homogeneous structure(s) with refractority ***(d ≥ 1)***
d–HSS – ***d***–dimensional homogeneous structure(s) with storage ***(d ≥ 1)***
DPDS – discrete parallel dynamic systems
ESP – elementary symmetrical polynomial(s)
FA – functional algorithm(s); depending on context
FGT – formal grammar theory
GDP – the global decomposition problem
GLDP – the generalized global decomposition problem
GLHS – the generalized linear classical structures ***d–HS (d ≥ 1)***
GTF – global transition function(s); depending on context
HCS – homogeneous computing systems *(environments)*
HPDT – heterogeneous periodically defined transformations
HS – homogeneous structure(s) {***HS, HS–models***}
HSoS – homogeneous structure(s) on splitting
HSR – homogeneous structure(s) with refractority
IAN – International Academy of Noosphere
IB – an internal block of the ***MEC***
ISG – isotonic structural grammar(s)
LBF – local block function(s); depending on context
LRA – locally realizable algorithms

LTF – local transition function(s); depending on context
MEC – mutually–erasable configurations
MEC–1 – the generalized mutually–erasable configurations
MTOHS – mathematical theory of homogeneous structures ***(Cellular automata)***
NCF – nonconstructible configuration(s) ***(Garden–of–Eden configurations)***
NCF–1 – nonconstructible configuration(s) of type ***1***
NCF–2 – nonconstructible configuration(s) of type ***2***
NCF–3 – nonconstructible configuration(s) of type ***3***
NI – neighborhood index of a structure ***d–HS (d≥1)***
NT – neighborhood template of a structure ***d–HS (d≥1)***
PADHS – parallel algorithm(s) defined by classical ***d–HS (d≥1)***
PBS – parallel block substitutions
PC – personal computer(s); depending on context
PCF – passive configuration(s); depending on context
PCS – parallel control system(s)
PDDS – parallel discrete dynamic systems
PDT – periodically defined transformations
PLG – problem of limited growth
PSIP – parallel system of information processing
RANS – Russian Academy of Natural Sciences
SAA – systems of algorithmic algebras
SPS – systems of parallel substitutions
SRC – self–reproducing configurations in the Moore's sense
SUDS – sequence of uniquely defined sums
TRG – Tallinn Research Group
TWPM – two–way pushdown machine(s)
TM^s_q – Turing machine with ***q*** internal states and ***s*** symbols on an input/final tape
UCF – universal configuration(s); depending on context
UHS – universal homogeneous structure(s)
UMT – universal Turing machine(s); depending on context
VCF – vanishing configuration(s); depending on context

Below, an abbreviation ***W*** is being understood in the singular or in the plural depending on a context. Other abbreviations are introduced as required. It is necessary to note that the results represented here bear a descriptive character inasmuch as their proofs are lengthy enough and too technical to be included in the book. The interested reader is referred to literature cited in the appropriate places of the book.

Introduction

First of all, a few words about the terminology used below. Today, the problematics of *Cellular automata* ***(CA)*** well enough is advanced, being quite independent field of modern mathematical cybernetics, having own terminology and axiomatics at existence of a rather broad sphere of various appendices. At the same time, it is necessary to emphasize, that at the assimilation of the given problematics in the Soviet Union in Russian-lingual terminology, whose the basis for the first time have been laid by us at ***1970,*** for the concept ***«Cellular automata»*** has been determined the term *«Homogeneous structures»* ***(HS; HS–**models**),*** which nowadays is the generally accepted term together with a whole series of other notions, denotations and definitions [1,16,114,119]. So, during the present monograph along with the given term the well–known its Anglo–lingual equivalent the ***«Cellular automata – CA»*** is used too.

Homogeneous Structure ***(HS) –*** a parallel information processing system consisting of intercommunicating identical finite automata. Although *homogeneous structures* will be used throughout this monograph as the usual term, it is necessary to keep in mind, that *cellular automata* ***(CA),*** *iterative networks* etc. are essentially synonyms. We can interpret ***HS*** as a theoretical basis of artificial parallel information processing systems. From the logical standpoint a ***HS*** is an infinite automaton with *specific* internal structure. The ***HS-**theory* can be considered as a structural and dynamical theory of the infinite automata. ***HS***–models can serve as an excellent basis for modeling of many discrete processes, representing interesting enough independent objects for research too. Recently, the undoubted interest to the ***HS***–problematics has arisen anew and in the given direction many remarkable results have been obtained.

So, the ***HS***–axiomatics provides such three fundamental properties as ***homogeneity, localness*** and ***parallelism*** of functioning. If in a similar computing model we shall with each elementary automaton associate a separate microprocessor then it is possible to unrestrictedly increase the sizes of such computing system without any essential increase of temporal and constructive expenses, required for each new expansion of the computing space, and also without any overheads connected to coordination of functioning of an arbitrary supplementary quantity of elementary microprocessors. Similar high–parallel computing models admit practical realizations consisting of rather large 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 defined by a 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 [536].

The above three such features as *high homogeneity*, *high parallelism* and *locality* of interactions are provided by the ***HS***–axiomatics itself, while such property important from the physical standpoint as ***reversibility*** of dynamics is given by software way. In light of the listed properties even classical ***HS*** are high–abstract models of the real physical world, which function in a space and time. Therefore, they in many respects better than many other formal architectures can be mapped onto a lot of physical realities in their modern understanding. Moreover the ***HS***-concept itself is enough well adapted to solution of various problems of modelling in such areas as mathematics, cybernetics, development biology, theoretical physics, computing sciences, discrete synergetics, dynamic systems theory, robotics, etc. Told and numerous examples available for today give rise us to the conclusion that ***HS*** can represent a rather serious interest as a new *perspective* environment of modelling and research of many discrete processes and phenomena, determined by the above properties; in addition, raising the ***HS***–problematics onto a new interdisciplinary level and, on the other hand, as an interesting enough independent formal object of researches.

The base modern tendencies of elaboration of perspective architecture of high-parallel computer facilities, a problem of modelling of discrete parallel processes, discrete mathematics and synergetics, theory of the parallel discrete dynamic systems, problems of artificial intellect and robotics, parallel information processing and algorithms, physical and biological modelling, along with a lot of other important prerequisites in various areas of modern natural sciences define at the latest years a new ascent of the interest to the formal *cellular* models of various type that possess high-parallel manner of action; the *homogeneous structures* are some of major models of such type. During time which has passed after appearance of monographs and the collected papers [1,3,4,5,7-10, 13,15,45,53-57,75,82,83,143,145,146,152-157,171,173,175,197,304,408,467] that have been devoted to various theoretic and applied aspects of the ***HS***–problematics (*it first of all concerns the works* [1,5,8,9,90,134,141,144-146,164,169,186,293,464]), the certain progress has been reached in this direction, that is connected, above all, with successes of the theoretical character along with essential expansion of fields of appendices of the ***HS***-models, mainly, in computer science, cybernetics, physics, biology and substantial growth of quantity of researchers in this field. Along with that, in the USA, Japan, Germany, the Great Britain, Estonia, etc., a series of works summarizing the results of progress in those or other directions of the ***HS*–**problematics including its numerous appendices in many areas has appeared. Our monographs at the substantial level have presented the reviews of the basic results received by the ***Tallinn Research Group*** on the ***HS*–**problematics during the ***40*–**year period of its creative activity, except eighteen–year break ***(1990–2008)*** caused by intensive enough work with diverse software**: *OS/360, Basic, Reduce, Pascal, MathCAD, Mathematica, Maple,*** etc. [10,93-118]. In the given period we prepared and published in Russia**,** USA**,** Lithuania**,** Estonia and Byelorussia a whole series of books in the stated directions along with development of software of all kinds for platforms ***Windows*** and ***DOS*.** In addition, in the same period the essential attention had been devoted to mathematics, statistics theory along with some other fields of natural sciences. For the reason stated above, active investigation in the ***HS*–**problematics, practically, was being not carried out.

From the very outset of our researches on the ***HS*–**problematics, above all, with application accent on mathematical development biology the informal ***Tallinn Research Group (TRG)*** consisting of the researchers of a few lead 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 broad enough bounds depending on the researched problems. In [1,7,9,10] the analysis of the ***TRG*** activity during ***30*–**year period which to some degree can be instructive and for research of the dynamics of development of the ***HS*–**problematics as an independent scientific direction as a whole is presented. Ibidem the basic directions of our researches can be found along with main received results.

Today, the homogeneous structures are being investigated from many standpoints and interrelations of the objects of such type with already existing problems are being discovered constantly. With the purpose of general acquaintance with extensive ***HS*–**problematics as a whole, and with its separate basic directions specifically, it is recommended to address to the interesting and versatile surveys of such researchers as ***V.Z. Aladjev, V. Cimagalli, K. Culik, D. Hiebeler, A. Lindenmayer, A.R. Smith, P. Sarkar, M. Mitchell, T. Toffoli, R. Volmar, S. Wolfram,*** et al. [536]. A series of books and monographs of such authors as ***V.Z. Aladjev, A. Adamatzky, E. Codd, A. Ilachinskii, M. Garzon, M. Duff, P. Kendall, T. Toffoli, B. Voorhees, M. Sipper, O. Martin, K. Preston, V. Kudrjvcev, N. Margolus, R. Vollmar, B. Voorhees, S. Wolfram,*** and certain others contain rather interesting historical excursuses into the ***HS*–**problematics**;** unfortunately, hitherto a common standpoint onto historical aspect in the given question does not exist [5,536,567,617]. In view of it, here is opportune moment to briefly emphasize once again our standpoint onto historical aspect of the ***HS*–**problematics, namely**:** a brief historical excursus presented below make it one's aim to define the basic stages of becoming of the ***HS*-**problematics, having digressed from numerous particulars. Having started own researches on the ***HS*-**problematics in ***1969*,** we on base of analysis of large enough quantity of publications and direct dialogue with many leading researchers in this direction possess the certain information concerning the objective development of its basic directions, above all, of theoretical character. That allows us with sufficient degree of objectivity to time the pivotal stages of its development**;** at that, many details of historical character concerning the ***HS*–**problematics the reader can find, for example, in a whole series of such works as [1,3,5,8-10,53-56,90,114,131,135,146,150, 161,163,179,186,230,264,265,271,536,567,617].

From the theoretical standpoint the concept of ***cellular automata* (*CA*;** *homogeneous structures***)** has been introduced at the end of the forties of the past century by ***John von Neumann*** on ***S. Ulam's*** advice with the purpose of determination of more realistic and well formalized model for research of behaviour of complex evolutionary systems, including self–reproduction of alive organisms. While ***S. Ulam*** oneself has used ***CA*–**like models, in particular, for research of the growth problem of crystals and some other discrete systems growing in conformity with recurrent rules. The structures investigated by him and his colleagues were, mainly, ***1*–** and **2–**dimensional, however higher dimensions have been considered too. In addition, questions of universal computability together with some other theoretical questions of behaviour of *cellular* structures of this type also were kept in view. A little bit later also ***A. Church*** started to investigate the similar structures in connection with works in the field of *infinite* abstract automata and mathematical logic.

The ***J. Neumann's CA*–**model has received the further development in works of his direct followers whose results together with the finished and edited work of the first one have been published by ***A.W. Burks*** in his excellent books [124,128], which have determined development of researches in this direction for some subsequent years. In process of researches on the ***HS*–**problematics ***A. Burks*** has created at university of Michigan the research team **«*The Logic of Computer Group*»,** from which a whole series of the first–class experts on the ***HS***–problematics has come out afterwards ***(T. Toffoli, J. Holland, R. Laing, et al.)***.

Meanwhile, considering historical aspect of the ***CA***–problematics, we should not forget an important contribution to the given problematics which was made by pioneer works ***Konrad Zuse*** and with which the world scientific community has familiarized oneself enough late and even frequently without his mention in the given 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 else ***– cellular automata (homogeneous structures)*** in the modern terminology [126,188,423]. At that, ***K. Zuse*** has supposed that physical processes in point of fact are calculations, whereas our universe is a certain «*cellular automaton*» [126]. In the late seventies of the last century such view on the universe was innovative while now the idea of the ***computing universe*** horrify nobody, finding a logical place in modern theories of some researchers working in the field of quantum mechanics [536]. Unfortunately, even at present the ***K. Zuse's*** ideas are unfamiliar even to rather meticulous researchers in this field. For exclusion of any speculative historical aspects existing occasionally today, in the future historical researches it is necessary to pay the most steadfast attention on the given essential circumstance. Namely therefore, only many years later the similar ideas have been republished, popularized and redeveloped in researches of other such researchers as ***T. Toffoli, E. Fredkin, S. Wolfram,*** et al. [5,536]. At that, the itself concept «***Cellular automata***» has been entered by ***John von Neumann.*** Perhaps, ***John Neumann,*** being familiar with ***K. Zuse*** ideas, could use cellular automata not only for simulation of process of self–reproduction, but also for creation of high-parallel computing models.

From more practical standpoint and game experiment the ***CA***–model has notified about itself in the late sixties of the last century, when ***J.H. Conway*** has presented the now known game ***«Life»***. The given game became rather popular and has attracted attention to *cellular* automata of both numerous scientists from various fields and amateurs [10,239]. At present, the game, probably, is the most known ***CA***–model**;** at that, it possesses the ability to self–reproduction and universal computings. Modelling a work of an arbitrary Turing machine by means of spatial-temporal dynamics of such ***CA***–model, ***J. Conway*** has proved ability of the model to universal computability. Later a rather simple way of realization of any boolean function in configurations of the «***Life***» has been suggested [536]. Thus, even such very simple ***CA*–**model turned out equivalent to the universal Turing machine. Furthermore, to this ***CA*–**model the significant interest and till now does not vanish, above all, to its computer realization [5,54-56,79,90,114,536,545,567,617].

Thus, early ideas and researches of such first-rate mathematicians and cyberneticians as ***K. Zuse, John von Neumann, S. Ulam*** and ***A. Church*** along with their certain direct followers we can ascribe with complete reason to the *first stage* of becoming of the ***HS*-**problematics as a whole [125-127,129-133,288-299]. The necessity for a good enough formalized environment for modeling of processes of biological development and above all of the self-reproduction process was being as one of the base prerequisites stimulating the ***HS*–**concept beginning. Thereupon, ***John Neumann*** and a whole series of his direct followers have investigated a series of questions of computational and constructive opportunities of the first ***HS*–**models. The above works at the end of the fifties of the last century have attracted to the problematics a lot of researchers [1,5, 124,128]. At that, *homogeneous* structures were being rediscovered not once and under various names – in the electrical engineering they are known as *iterative networks*, in pure mathematics they are known as a section of *topological dynamics*, in biology – as *cellular structures*, etc.

As *second stage* in becoming of the ***HS*–**problematics it is quite possible to consider the publication of the widely known works of ***E.F. Moore*** and ***J. Myhill*** on the *nonconstructability* problem in *classical* ***HS*-**models that along with solution of some mathematical problems have become in a sense by the *accelerators* of the activity which attracted a steadfast enough attention to the given problematics of a lot of mathematicians and researchers from other fields [123,274,275]. In particular, we have familiarized oneself with the given ***HS*–**problematics in ***1969*** owing to Russian translation of the excellent proceedings edited by ***R. Bellman,*** that contain known articles of ***E.F. Moore, S. Ulam*** and ***J. Myhill*** [123]**.** Scientific groups on the ***HS*–**problematics in the *USA*, *Germany*, *Japan*, *Hungary*, *Italy*, *France*, and *USSR* ***(TRG, 1969)*** are formed up. At that, the further development and popularization of the ***CA*–**problematics can be connected with names of such researchers, as ***E. Codd, S. Cole, E. Moore, J. Myhill, E. Banks, H. Yamada, S. Amoroso, J. Buttler, V.Z. Aladjev, J. Holland, G. Herman, A.R. Smith, T. Yaku, A. Maruoka, Y. Kobuchi, G. Hedlund, M. Kimura, H. Nishio, T. Ostrand, A. Waksman*** and a whole series of others whose works in the sixties – the seventies of the last century have attracted attention to the given problematics from the theoretical standpoint; they have solved and formulated a lot of rather interesting problems [536]. Later, mathematicians, physicists, and biologists began to use the cellular automata with the purpose of simulation of own specific problems. So, in the early sixties – the late seventies of the last century the numerous researchers have prepared entry of the ***HS***–problematics into the current stage of its development being characterized by union of earlier *disconnected* ideas and methods on the general conceptual and methodological platforms, along with a rather essential expansion of fields of its appendices.

We can attribute the beginning of the ***third period*** to the early eighties of the last century when to the ***HS***–problematics special interest again has been renewed in connection with rather active researches on the problem of artificial intellect, physical modeling, elaboration of a new perspective architecture of high-parallel computer systems, and other important motivations. So, in our opinion namely since works of such researchers as ***Bennet C., Grassberger P., Boghosian B., Crutchfield J., Chopard B., Culik II K., Gács P., 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 ***HS*** as an environment, above all, of physical modelling began [536].

At present, ***CA***–problematics are being widely studied from extremely various standpoints, and interrelations of such *homogeneous* structures with existing problems are constantly sought and discovered. A series of rather large teams of researchers in many countries and, first of all, in the USA, Germany, the Great Britain, Italy, France, Japan, Australia deals with the given problematics. Active enough scientific activity in this direction was carried out and in Estonia within of the ***TRG*** whose a whole series of results has received an international recognition and has made up essential enough part of the modern ***HS***–problematics.

Annual national and international scientific forums of a various level on ***HS***–problematics and its applied aspects are held. The number of publications in various periodic and nonperiodic editions **(***in the USA since **1987** on **HS**–problematics the special journal **«Complex Systems»** is being issued***)** along with special monographs, books, proceedings and collections are annually published**;** the national programs on the ***HS***–problematics are developed, what with good reason allows to speak about constantly growing interest to the given problematics [121,536]. Since ***1987 HS***–problematics all is more widely represented at various international conferences on mathematical and computer modeling at level of sectional and plenary reports. Definition of a special index in the classification ***AMS*** for the ***HS***–problematics, assignment of special sections in mathematical encyclopedias, active attempts of creation of the advanced classification of directions in the ***HS***–problematics along with creation under the aegis of the ***IFIP*** of the international working group on *cellular automata* can be quite unambiguously considered as definition of a new independent scientific direction of researches [119, 129,443,536]. The users of ***Internet*** receive an access to the information on the given problematics by key phrases «***homogeneous structures***» and «***cellular automata***», including such questions as research teams, the scientific forums, separate works, the bibliography together with a lot of many other important aspects of the ***HS***–problematics.

The modern standpoint on the ***HS (CA)*** theory has been formed under the influence of works of such researchers as ***Adamatzky A.I., Aladjev V.Z., Amoroso S., Arbib M., Bagnoli F., Bandini S., Bandman O., 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., Cole S., Codd E.F., Crutchfield J., Culik K.II, Das A.K., Durand B., Durret R., Fokas A., Fredkin E., Gács P., Gardner M., Gerhardt M., Griffeath D., Golze U., Grassberger P., Green D., Gutowitz H., Hedlund G., Honda N., Hemmerling A., Holland J., Ibarra O., 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., Richardson D., Sarkar P., Sato T., Shereshevsky M., Sipper M., Smith A.R., Sutner K., Takahashi H., Thatcher J., Toffoli T., Toom A., Tseitlin G.E., Varshavsky V., Vichniac G., Vollmar R., Voorhees B., Waksman A., Weimar J., Willson S.J., Wolfram S., Wuensche A.A., Yaku T.,*** and other numerous researchers from many countries.

Along with our works in the ***HS*** theory, it is necessary to note a whole series of other Soviet researchers who have received in the given field both fundamental and considerable enough results at the sixties – the eighties of the last century. They are ***Adamatzky A.I.*** (*identification of* ***HS***), ***Bandman O.L.*** (*asynchronous* ***HS***), ***Blishun A.*** (*growth of patterns*), ***Bliumin S.L.*** (*growth of patterns*), ***Bolotov A.A.*** (*simulation among classes of* ***HS***), ***Varshavsky V.I.*** (*synchronization of* ***HS***, *simulation of anysotropic* ***HS*** *on the isotropic ones*), ***Georgadze A., Matevosian A., Mandzhgaladze P.*** (*growth of the configurations; universal stochastic and deterministic* ***HS***, ***HS*** *and parallel grammars*), ***Dobrushin R.L., Vasil'ev N., Stavskaya O., Mitiushin L., Leontovich A., Toom A.,*** (*probabilistic* ***HS***), ***Ikaunieks E.***

(nonconstructible configurations), ***Koganov A.V.*** *(universal **HS**, stationary configurations, simulation of **HS**)*, ***Kolotov A.*** *(models of excitable media)*, ***Levenshtein V.*** *(synchronization in **HS**)*, ***Levin L.A.*** and ***Kurdiumov G.L.*** *(stochastic **HS**)*, ***Makarevskii A.I.*** *(implementation of boolean functions in **HS**)*, ***Petrov E.I.*** *(synchronization of **2D–HS**)*, ***Podkolzin A.S.*** *(simulation of the **HS**; asymptotic of the global dynamic; universal **HS**)*, ***Pospelov D.A.*** *(homogeneous structures and distributed AI in **HS**)*, ***Prangishvili I.V.*** *(**HS** architectures of high-parallel processors)*, ***Reshod'ko L.S.*** *(**HS**–models of the excitable media)*, ***Revin O.M.*** *(simulation of anysotropic **HS** on the isotropic **HS**)*, ***Solntzev S.*** *(growth of patterns)*, ***Tzetlin M.*** *(collectives of automata, games in **HS**)*, ***Tzeitlin G.E.*** *(algebras of shift registers)*, ***Scherbakov E.S.*** *(universal algebras of parallel substitutions)*, and a series of others.

It is supposed that the ***HS***–models can play extremely important part as both conceptual and applied models of *spatially-distributed* dynamic systems among which first of all an especial interest the *computational*, *physical* and *biological* cellular systems represent. In the given direction already takes place a rather essential activity of a lot of the researchers who have received quite encouraging results [3-5,8,9,15,69,90,145,146, 153,155-157,161,162,197,269,275,355,536]. At last, theoretical results of the above-mentioned and of a lot of other researchers have initiated a modern mathematical ***HS***–theory evolved to the current time into an independent branch of the abstract automata theory having numerous interesting appendices in various areas of science and technics. Above all, in such fields as physics, development of perspective architecture of high–efficiency computer systems, parallel information processing, development biology, computing sciences and informatics, which are linked to mathematical and computer modeling, etc., by substantially raising the ***HS***–concept onto a new interdisciplinary level.

Meanwhile, the separate researchers in a burst of certain euphoria try to represent the ***HS***–approach as an 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*** [407]. Above all, the book contains many results which have been received much earlier by a series of other researchers on the ***HS***–problematics, including the Soviet authors (*see* [1,3-5,8,9,53-57,80,82,83,127-135,137-142,150-161,169-171,175-179,182-191,195-201,230-233,240,241,536] *and many others*). Furthermore, many fundamental results in this direction belong to other researchers. The unhealthy vanity of the author of the given book does not allow him to look without bias on history of the

HS–problematics as a whole. In general, ***Wolfram*** enough frivolously addresses with authorship of the results received in ***HS***–problematics of what there can be an impression **-** everything made in this direction belongs basically to him. At that, the book contains basically results of computer experiments with very simple types of ***HS***–models, drawing the conclusions and assumptions on their basis with doubtful enough 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 ***Wolfram*** passages and inferences similar to them cause utterly certain doubts in the scientific decency and judiciousness of their author.

At last, we absolutely do not agree that ***Wolfram*** book presents a new kind of science, nevertheless his book would be more pleasant to read if he were more modest. In our opinion, this book represents in many respects a speculative sight both on ***HS***–problematics, and on science as a whole. Here we only shall note, contrary to the pursued purposes the given book not only was not revelation for the experts working in the ***HS***–problematics, but also to a certain extent has caused a little bit deformed representation about the researches area that is perspective enough from many standpoints. With relatively detailed standpoints concerning the above book the reader can familiarize oneself in works [536,567,617] and some others. Meanwhile, in spite of the told above concerning the given book, it can represent the certain interest, taking into consideration the marked and other certain remarks.

By a certain contraposition to the standpoint on the ***HS***–problematics that is declared by the above book [407] our vision of this question is being represented as follows. Our experience of researches in the ***HS***–problematics both on theoretical, and especially applied level speaks entirely about another, namely**:**

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

(2) HS-models can serve as a quite satisfactory model of high-parallel calculations just as the Turing machines (Markov normal algorithms, Post machines, productions systems, etc.) serve as the formal models of sequential calculations; from this standpoint the HS–models it is

possible to consider and as algebraical systems of processing of finite or/and infinite words, defined in finite alphabets, on basis of a finite set of rules of parallel substitutions;

(3) principle of local interaction of elementary automata composing a HS–model which in result defines their global dynamics allows to use the HS and as a fine environment of modeling of a rather broad range of processes, phenomena and objects; furthermore, the phenomenon of reversibility permitted by the HS does their by very interesting means for physical modeling, and for creation of very perspective computing structures basing on the nanotechnologies;

(4) HS–models represent a rather interesting independent mathematic object whose essence consists in high–parallel processing of words in finite alphabets.

At that, it is possible to associate the ***HS***–approach with certain model analogue of the differential equations in partial derivatives describing those or another processes with that difference, that if the differential equations describe a process at the average, in a ***HS***–model defined in appropriate way, a certain researched process is really embedded and dynamics of the ***HS***–model enough evidently represents the *qualitative* behaviour of researched process. Thus, it is necessary to determine for elementary automata of the model the necessary properties and rules of their local interaction by appropriate way. The ***HS***–approach can be used and for research of processes described by complex differential equations which have not of analytical solution, and for the processes, that it is not possible to describe by such equations. Along with it, the ***HS*** represent a rather perspective modelling environment for research of those phenomena, processes, phenomena and objects for that there are no known classical means or they are difficult enough.

As we already noted, as against many other modern fields of science, the theoretical component of the ***HS***-problematics is no so appreciably crossed with its second applied component, therefore, it is possible to consider the ***HS***–problematics as two independent enough directions: ***(1) research of the HS as mathematical objects and (2) usage of the HS for simulating;*** at that, the *second* direction is characterized also by the wider spectrum. At that, the level of evolution of the second direction is appreciably being defined by possibilities of the modern computing systems since ***HS***–models, as a rule, are being designed on base of the *immense* number of elementary automata and, as a rule, with complex enough rules of local interaction among themselves. The indubitable interest to them amplifies also a possibility of practical realization of high-parallel computing ***HS***–models on the basis of modern successes of microelectronics and prospects of the information processing at the molecular level *(methods of nanotechnology)*; while the itself ***HS***-concept provides creation of both conceptual and practical models of *spatially–distributed* dynamic systems of which namely physical systems are the most interesting and perspective. Indeed, models which in an obvious way reduce ***macroscopic*** processes to rigorously defined ***microscopic*** processes, represent especial epistemological and methodical interest for they possess the great persuasiveness and transparency. Namely, from the given standpoint the ***HS***–models of various type represent a special interest, above all, from the applied standpoint at research of a lot of processes, phenomena and objects in different fields and, first of all, in physics, computer science and development biology.

The *first* direction enough intensively is developed by mathematicians while contribution to development of the second direction essentially more representative circle of researchers from various theoretical and applied fields *(physics, chemistry, biology, technics, etc.)* brings. Thus, if theoretical researches on the ***HS***-problematics in general are limited to *classical, polygenic* and *stochastic* ***HS***–models, then the results of second direction are based on essentially wider representation of classes and types of ***HS***–models. As a whole if classical ***HS***–models represent first of all the formal mathematical systems researched in the appropriate context, then their numerous generalizations represent a perspective enough environment of modeling of various processes and objects.

It is necessary to pay more steadfast attention and to a question of ***HS*** popularization and their applied possibilities in various fields. Above all, new successful examples of application of the concept, results and methods of the ***HS***–problematics in other areas will promote it. Thus, we come to necessity of essentially more active application of the ***HS***–concept for various fields of science and technics. And that, indeed, is a important enough, complex and multifold problem, promotional to properly the further development of the ***HS***-problematics. Once more, one should not to condescend both to exaggerated popularization and to obviously speculative representation of the ***HS***–concept as a certain all-powerful means of knowledge of complex enough outward things, and it would be rather naive to reduce it to some ***HS***–models. Or else, the serious scientific community will enough skeptically think about such potentially important direction of modern cybernetics, what will has a pernicious influence both upon the ***HS***–problematics, and upon its many existing and potential appendices [536,567,617]. Meanwhile, and as independent mathematical object the homogeneous structures ***(****callular automata****)*** not carry in our opinion the fundamental character, making up one far from the very complex of subclasses of the class of all parallel discrete dynamic systems. The overwhelming majority of theoretical results on cellular automata is reduced to their research by means of known mathematical approaches, not introducing anything fundamental. Thus, objects of such type are of interest, above all, from the applied points of view in those fields where such essential factors play a principal part as uniformity, localness of interaction along with high–parallel principle of functioning. At that, it is necessary to mark once more what that is our private standpoint however formed under influence of a whole series of essential enough prerequisites.

In what follows**,** we present our main results of the research we have done in mathematical theory of the ***classical homogeneous structures (HS;*** *synonym «Cellular Automata»****)*** during ***1969 – 2010.*** Indeed, we have done much more, specifically, in such fields as mathematics, software, statistics, cybernetics, computer science, technology and mathematical theory of homogeneous structures. Much of these investigations have been stimulated by scientific program of *Tallinn Research Group* ***(TRG)*** and then of *International Academy of Noosphere* ***(IAN).*** Now, the *cellular automata* ***(CA)*** problems is a well enough developed independent field of the modern mathematical cybernetics that has considerable sphere of appendices. In this book a number of fundamental problems of the ***HS***–problematics is considered on the example of classical ***HS***–models forming up the certain base of the ***HS***-concept as a whole. At the same time, the themes considered in the book represent a rather transparent and simple model both for mastering of ***HS***–conception and principal concepts, and base results of the modern ***HS***–problematics as a whole.

The classical ***HS***–model is chosen as base since it is a basis or a direct prototype of all most known ***HS***–like models ***(****homogeneous computing environments****,*** *cellular processors and structures****,*** *systolic structures****,*** *neural and iterative networks****,*** *etc****.)*****,** not requiring special knowledge from a lot of sections of mathematics, cybernetics, etc. In addition, the theory of classical ***HS***–models for today is the most investigated and advanced as quite independent mathematical problematics.

In the conclusion once again it is necessary to note a rather important circumstance, at discussion of the *classical* homogeneous structures we emphasize the following rather essential moment. We considered the

HS–models that are a class of *parallel discrete dynamic systems* as formal *algebraic systems* of processing of finite words ***(configurations)*** in finite alphabets without any reference, as a rule, to their microprogrammed environment, i.e. without use of their cellular organization on lowest level inherent in them, what distinguishes our approach to research of the given objects from approaches of a lot of other researchers.

At such approach the ***HS–***models are considered at especially formal level, not allowing in full measure to utilize their intrinsic property of high parallelism in area of computations, and information processing as a whole. Naturally, for solution of a lot of applied problems in the ***HS–***environment and obtaining of a series of thin results, first of all, of model character an approach at a microprogram level is needed when a researched process, algorithm or phenomenon is directly embedded into an environment, using its concrete parameters: a dimensionality, a neighbourhood index, a state alphabet and local transition function. In case of such approach it is possible to receive solutions for a lot of important concrete appendices along with generalizations of a rather high level of theoretical character. In particular, by direct embedding of the universal computing algorithms or logical elements into objects of the given kind, it is possible to constructively prove existence of the property of universal computability of homogeneous structures, etc.

Meanwhile, having a lot of cogent advantages, the above so-called the ***direct*** approach to research of structures does not allow to receive in a lot of cases the results describing them as the especially mathematical objects, demanding use of methods and results of more abstract areas of modern mathematics. So, a *reasonable* combination of both specified approaches to investigation of such class of dynamic discrete systems, as the *homogeneous structures*, seems the most natural, in our opinion.

The ***HS–***problematics questions considered in the present monograph, in many respects were conditioned by own interests and tastes of the author, along with traditions of creative activity of the *Tallinn Research Group* in the given direction. However, already on basis of the offered results, the reader can receive a quite definite situation of the modern state and problematics of some basic areas of the mathematical theory of ***HS-***models and some their applied aspects. At last, it is necessary to note, at present the ***HS–***problematics is in a stage of intensive enough development and the further work in the given direction is extremely desirable from many points of view and, above all taking into account interdisciplinary character of the general ***HS–***concept.

Contents of the proposed book can be briefly characterized as follows. The ***first*** chapter presents the basic conception of *classical homogeneous* structures, including the basic concepts, definitions and designations. The basic types of homogeneous structures ***(HS-****models)* are defined; at that, a draft architecture of the ***HS–***theory and its appendices together with basic means of research in this direction are briefly discussed.

The ***second*** chapter deals with the nonconstructability problem for the classical homogeneous structures, beginning with certain preliminary information concerning the given problematics. Then, four main types of the nonconstructability in *classical* ***HS-***models are introduced; along with the basic nonconstructability type ***(NCF)*** additionally three types of the nonconstructability ***(NCF–1, NCF-2, NCF-3)*** are determined that allow to investigate essentially more in detail the dynamics of *classical* structures. In this chapter such questions as criteria of existence of *base* types of nonconstructability in classical structures, algorithmic aspects of the nonconstructability problem along with the *reversibility* problem of dynamics of classical structures together with a series of connected questions of dynamics of classical ***HS–***models are considered.

The ***third*** chapter consideres so-called extremal constructive resources of classical ***HS–***models among which accent is done on universal and self–reproducing finite configurations. Whereas in the ***fourth*** chapter the complexity problem of finite configurations in classical structures is discussed. Parallel formal grammars and parallel languages defined by ***HS–***models of the certain types are considered in the ***fifth*** chapter.

In the ***sixth*** chapter the modeling problem in classical structures along with related questions is considered. Here such questions as modeling of known *formal* algorithms by means of classical structures, modeling of classical structures by structures of the same class, formal parallel algorithms defined by classical one-dimensional structures along with some special questions of modelling in classical structures linked with their dynamics can be noted.

In the ***seventh*** chapter the decomposition problem of global transition functions in classical ***HS-***models is considered. Here such questions as decomposition of special global transition functions, some approaches to solution of the general decomposition problem, certain questions of *solvability* of the decomposition problem of global transition functions, the complexity problem of global transition functions can be noted. In addition, a series of interesting enough questions directly linked with this problem is discussed too.

At last, the ***eighth*** chapter deals with the certain applied aspects of the ***HS***–problematics. The questions of use of the ***HS***–approach to solving of certain rather important problems in pure mathematics and biology of development are considered. So, the first direction is presented by a solution of a interesting enough combinatory problem of ***H. Steinhaus*** along with a ***S. Ulam's*** problem from theory of numbers. Whereas the second direction presents such aspects in biological sciences as formal discrete models of self-reproduction, modeling of processes of growth in homogeneous structures of various types along with ***HS***–models of differentiation, regulation and regeneration. Along with above themes the application of ***HS***–models of different types in computing sciences and a whole series of other fields is discussed.

We pass on now to the direct consideration of the basic aspects of the ***classical homogeneous structures*,** having introduced previously the paramount concepts, definitions and designations. At that, the other basic elements will be introduced as required. It is necessary to mark, that with a view to decrease volume of the book by reason of essential extensiveness of the material in overwhelming majority the presented results carry in a great extent the intensional character which in most cases are supplemented with most essential requisite illustrations and clarifications. Whereas with rigorous proofs **(***at times rather volumetric***)** of the presented results the reader can familiarize oneself in the cited original sources. In addition, the examples quoted in the monograph for acknowledgement of corresponding assertions are simple enough, having much more complex analogues however they allow the reader enough simply to carry out all necessary verification. Unfortunately, restricted volume of the book had not allowed to us to consider a lot of interesting enough considerations on the given problematics but they also can be found in the cited literature. In short, the represented material having brief character and concise considerations is intended above all for a wide enough circle of the readers which at times are far from any necessary grounding in the given problematics.

Extensive bibliography, in turn, contains numerous references to a lot of other sources in this direction, allowing to the more exacting reader to receive more detailed information on many important questions of the given problematics and of the considered here, and the residuary ones for whatever reasons outside of limits of the present monograph**;** in addition, the more comprehensive bibliography supplementing the presented here can be found, for example, in bibliography [114,536].

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During researches in the theory of homogeneous structures extensive enough bibliography of original sources of different level and directly in the theory, and in its numerous applications in different fields has been collected by us. Naturally, the given bibliography is not perfectly exhaustive, however it can present the certain interest for researchers in the given field, first of all, of the beginners. Meanwhile, the reader has an opportunity to supplement the presented bibliography by the materials which are absent in it. We hope, that the given bibliography will allow to outline better both the circle of researchers in the given field, and breadth of scope of the problems considered by them. First of all, it concerns Soviet and Russian researchers who have received a series of priority results of fundamental character with which English-speaking researchers are familiar insufficiently well or are not familiar entirely. Subsequently some of them have been rediscovered by other researchers. It is especially topical and for the reason, that some Soviet researchers directly stood at the beginnings of the forming up of this area of modern mathematical cybernetics. The presented bibliography is not annotated, basically, however the headings of a great many of publications give the defined enough comprehension concerning the contents of the quoted material. The more extensive bibliography of original sources on the ***HS***–theory and its numerous appendices can be found in [536], while the skilled reader is referred to Internet with appropriate key phrases. In particular, a number of our works along with works of other writers can be found in the Internet. While here a incomplete list of our works we have done in the mathematical theory of classical homogeneous structures during ***1969 – 2010,*** in truth with considerable enough pauses caused by other themes is presented.

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