Philosophical foundations of technology and society

Мировоззренческие основы технологии и общества

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REVIEW ARTICLE

A discussion of S.M. Krylov's book "Neocybernetics" (2008)

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Abstract. A comparative analysis of the "general formal technology (GFT)" by S. M. Krylov is carried out in the context of the published book of the authors "General Theory of Technologies and Microelectronics" (2020) and on the basis of his work of 2008. Despite the abstractness of the algebraic-algorithmic approach, Krylov offers a number of specific constructions that are in demand during the fourth industrial revolution and for the future development of industrial technology in nanoelectronics and biotechnology. Industrial technology is considered as a complex object of management, i.e., it is the object of study of the new discipline "neocybernetics". Although the foundations of this approach were laid in 1930s–1960s within the framework of logical and mathematical research, its expansion is inevitable when using self-organization processes to obtain functional supramolecular structures in technological processes of nanoelectronics (for example, DNA origami engineering). The issues of complexity quantification for a product itself (structure) and its manufacturing technology, or, according to Krylov, the complexity of technological automata, have become even more relevant than before. The theoretical issues of self-organization, the development of artificial life, and the creation of self-replicating technical systems also seem promising for solution. In our opinion, Krylov's formal technology is an important "block" in the advancement of general theory of technologies (GTT) useful for describing the technology at the levels: operation, route, and process. We would like to encourage a wide range of readers to study the book and form a steady interest in general technological issues. The value of GTT and GFT extends beyond the sphere of technology and, in a narrow sense, factory production, but also into the area of "fine" regulation of physiology in biological objects and pharmacy, as well as into the problem field of cognitive sciences, psychology, and education. when the focus is on the personality structure and heterogeneous constructs "floating in the sea of the unconscious". Both S.M. Krylov and we demonstrate that the issues of industrial technology cannot be considered without abstract formalization and without reference to philosophy.

Keywords: general technology theory, formal technology, neocybernetics, finite-state machines, synergetics, complexity

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РЕЦЕНЗИЯ

Дискуссия по книге С.М. Крылова «Неокибернетика» (2008)

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Резюме. В контексте вышедшей книги авторов «Общая теория технологий и микроэлектроника» (2020) проводится сравнительный анализ «общей формальной технологии (ОФТ))» С.М. Крылова на основе его работы 2008 года. Несмотря на абстрактность алгебраико-алгоритмического подхода, Крылову удалось предложить ряд конкретных конструкций, востребованных в ходе четвертой промышленной революции и для будущего развития промышленной технологии наноэлектроники и биотехнологии. Промышленная технология рассматривается как сложный объект управления, т.е. выступает объектом изучения новой дисциплины «неокибернетика». Хотя основы данного подхода закладывались в 1930–1960 годах в рамках логико-математических исследований, но его расширение неизбежно при использовании процессов самоорганизации для получения функциональных надмолекулекулярных структур в технологических процессах наноэлектроники (например, инженерия ДНК-оригами). Вопросы исчисления сложности самого изделия (конструкции) и технологии его изготовления, или, по Крылову, сложности технологических автоматов, стали еще более актуальными, чем раньше. Теоретические вопросы самоорганизации, разработки искусственной жизни, создания самовоспроизводящихся технических систем также представляются перспективными для решения. Формальная технология Крылова выступает, по нашему мнению, важным «блоком» при построении общей теории технологий (ОТТ), полезным для описания технологии на уровне технологических: операции, маршрута и процесса. Хочется побудить широкий круг читателей к прочтению книги и сформировать устойчивый интерес к общетехнологической проблематике. Значение ОТТ и ОФТ простирается за пределы сферы техники и, в узком смысле, заводских производств, в область «тонкой» регуляции физиологии в биологических объектах и фармацевтика, а также в проблемное поле когнитивных наук, психологии, образования, когда в центре внимания оказываются структура личности и гетерогенные конструкты, «плавающие в море бессознательного». Мы, как и С.М. Крылов, демонстрируем, что вопросы промышленной технологии нельзя рассматривать без абстрактной формализации и без обращения к философии.

Ключевые слова: общая теория технологий, формальная технология, неокибернетика, конечные автоматы, самоорганизация, сложность

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INTRODUCTION

In the paper, we would like to pay tribute to the memory of Sergey Mikhailovich Krylov (1948–2020), Doctor of Technical Sciences, Professor of the Computer Department at Samara State Technical University, who has contributed to the creation of the general theory of technologies (GTT) [1]. Krylov's system of ideas on the formal theory of technologies (GFT, sometimes simply FT), as he called it, is presented in several papers [2], his dissertation [3], and three books [4–6]. Although the paper aims to compare the GTT and GFT, it would be appropriate to refer directly to only one book entitled "Neocybernetics" [5] (Fig. 1) fallen into the category of rare books. To understand the genesis and relationship between Krylov's ideas beyond the scope of the GFT and GTT, the synopsis review form is chosen by the authors. The book itself is written in a popular science style rather than in a scientific one. It should be noted that the term "neocybernetics" is increasingly used by different authors [7] while the distinction with Wiener cybernetics is along the lines of the control object complexity and, accordingly, incomplete information on its state. Any technological system can be considered just as a control object of higher complexity.

Fig. 1. S.M. Krylov and his book cover [5][1]

To clarify the subject of the GTT and GFT study, it would be appropriate to quote one passage used by Krylov and other authors as well. In the article "Technology" published in 1901 in the Brockhaus and Efron Encyclopedic Dictionary, D.I. Mendeleev characterizes technology as the science dealing with producing artificial objects, i.e., objects that do not exist in nature, from natural raw materials:

"The technology is the doctrine of advantageous (i.e., absorbing the least human labor and energy of nature) methods of processing natural products into the ones needed (necessary or useful, or convenient) for use in human life. Although technology is profoundly different from socioeconomic doctrines by its subject, it has rather many direct and indirect relations with them, since the economy (saving) of labor and material (raw material), as well as time and forces through them, is the first priority task of any production. And the essence of the factory production doctrine loses its ground completely if the production advantageousness (economy) is overlooked... The task of technology shows that it does not have those highest and absolute requirements which the abstract sciences related to the visible or internal nature have, that it contains in itself the application of other more abstract knowledge to life, and that its content must change according to the circumstances and conditions of place and time. However, these, so to speak, negative aspects of technology are redeemed, firstly, by the direct and vital importance, which factories and plants already have nowadays and which must strengthen more and more in the future. Secondly, by the fact that the doctrine of the methods used by plants and factories illuminates via scientific principles what is produced by practice. Through this not only the production is improved but also the scope of scientific understanding of things and phenomena is expanded" [8].

[1] URL: http://vt.samgtu.ru/index.php. Accessed: October 25, 2021 (in Russ.).

BOOK COMPOSITION

The Preface and Introduction provide the following three sources inspiring Krylov: "Tektology" by Bogdanov [9], "Notes by the Translator" by Augusta Ada Lovelace (1843), and works on synergetics. It should be reminded that Bogdanov has defined tektology as a general organizational science with emphasis placed on forms of organization (thus, "regulating forms" anticipate cybernetics). Why is the world organized? – this question arises for Krylov as well, so he writes: "The main goal of GFT is to try to explain logically (and technologically) the structure of the world around us at the level, first of all, of our perception, that is at macroscopic level, which 'scale center' is man himself. And the way this macrolevel can be realized in terms of different possible physical microlevels is kind of a secondary issue that is not considered here" [5, p. 11]. At the same time, "formal technology, on the contrary, starts from studying the most general properties of the most general operations on both real and imaginary (abstract) objects, moving down in the hierarchy towards more and more specific properties of more and more specific objects and operations" [5, pp. 6–7]. For better understanding, reference should be made to Bogdanov himself [9, p. 79]: "With the infinitely rich material of the Universe and the infinite variety of its forms, where can these persistent and systematic, repeating, and increasing, with the growth of knowledge, analogies come from? To regard them as 'incidental coincidences' is to introduce a great arbitrariness into the world-view and even to come into obvious contradiction with the theory of probabilities. There can be only one scientifically justified conclusion: the actual unity of organizational methods is found everywhere – in mental and physical complexes, in living and dead nature, in the work of spontaneous forces and the conscious activity of people." According to Bogdanov, Krylov represented formative forms as the development of systems: "The development of any system—material or informational—is a technological process to some extent. Therefore, a very important application area for formal technology is the most various development processes which we shall further call evolutionary: both natural existing in the surrounding environment and artificial realized by man or with his participation" [5, p. 9]. It should be noted that Krylov pursues the ideas of evolution more consistently, compared to the GTT, although evolution is considered here [1] not only in terms of technology but also in terms of technological operation (TO). Evolutionarity, manifesting itself in the technosphere through the creative activity of the spirit [1, p. 380], is a universal natural feature:

"In nature, through the chaos of innumerable variations, the same dialectical laws of motion that dominate the seemingly random events in history as well, being the same laws that run like a golden thread through the evolution of human thinking to gradually sink into the mind of thinking people, are paving their ways" [10].

Borrowed from Ada Lovelace, Byron's daughter, the view of TO captures the systematicity of the object being modified, in addition to abstractness: "By the word operation we mean any procedure changing mutual relationship between two or more things, whatever kind of relationship they may be. This is the most general definition including all objects in the Universe. But the science of such operations being specifically derived from mathematics is an independent science having its own theoretical validity and significance, just as logic has its own validity, regardless of the objects to which its explanations and methods are applied." In the GTT, TO is introduced as a change in the state of the substratum, but Krylov specifies any change as a change in the mutual relationship between parts. Then, Krylov identifies informational and "ordinary" material technologies according to the object types. The former is studied by the classical theory of algorithms [5, p. 11]: "Being the flesh and blood of mathematics (theory of algorithms, to be more exactly), GFT may adapt any of its methods developed so far to its needs without too much trouble. Moreover, the formal technology defines also the place of mathematics itself (as a computing technology) among all the many technologies very clearly." This is in compliance with our definition of technology as "the objectification of widely used algorithms" [1, p. 30].

We paid attention to the complexity when considering the level of technological route (TR). Krylov goes a little further, linking quite rightly the complexity with self-organization and thus, with synergetics (represented by Prigozhin primarily). He writes about synergetics and GFT: "Mutual recognition and 'exchange of ideas' may benefit both scientific areas, whereas a possible confrontation is likely to reflect only the typical social situation of 'power seizure.'" It should be noted that synergetics connects holistic perception with the search for order parameters in the research object; i.e., there must be order in any object, and the task of synergetics is the search for it. Krylov also writes about the constructive nature of GFT up to the construction of new "physical worlds", and, in our opinion, this only further focuses on the design technologies as twin ones in relation to the "manufacturing" technologies, as A.A. Ivlev has written [11]. In any case, studying self-organization problems cannot be separated from those of the complexity calculus.

The focus on constructiveness represents, perhaps, the most original feature of Krylov's approach consisting in "ultimate abstracting the notions of operation objects and mechanisms of linking objects to each other into various constructs and structures, whether it would be the words consisting of symbols, units and aggregates consisting of parts, or 'molecules' built of 'atoms'... It should be noted that it took about ten years to develop this seemingly very crude and very simplified approach" [5, pp. 15–16].

Chapter 1 entitled "Formal Technology and Metaphysics" is historical and bibliographic in nature, while Chapter 2 entitled "What Does Functionality Give?" focuses on defining GFT. In our book, we have done exactly the same, while the notions of "product," "target product," and thus functionality, are put at the forefront of the GTT as well. Chapter 3 entitled "Up the Ladder of Evolutionary Technologies" introduces the dynamic and evolutionary nature into GFT, but at the same time, the concept of hierarchy is naturally introduced [1, p. 69]. Not only changes in structures implementing each operation but also certain technologies and their evolutionary transformations, operations and working transitions of these operations, the role and nature of operations, and the change of this role during evolution may be analyzed. Thus, the evolution of microelectronics [1, Chapter IV] illustrates a general case of the technology evolution. Here, the evolution of processes as well as the evolution of the means implementing these processes are considered.

The next two chapters entitled "Why and How Life Emerges" and "Evolution of Systems" deal with the problems being fashionable in the 1960s, the discussions on which will be, certainly, continuing. Krylov refers to the concepts of entropy, negentropy, and adaptation mechanisms; and it is easy to see parallels with compositions of the fourth and fifth chapters [1] in this. Adaptability and homeostasis are important concepts when discussing the industrial technology. Chapters 6 and 7 on program-controlled technological systems of the future and Church's thesis, respectively, illustrate technical aspects of the production organization. Here, there is also some parallel with the chapters of our book on levels of production process and technology. Chapter 8, "How and Where Do We Develop To? Social and Economic Systems," where the focus is made on human aspects, e.g., beauty, is analogous to the last, seventh chapter [1], at least as far as the considered problem is concerned.

CONTENT AND DISCUSSION OF CHAPTER 1

Chapter 1 begins with a lengthy discussion of man's knowledge of the world gained through religion and then philosophy as well as through the unity of metaphysics and mathematics in terms of the number concept: "This was how the Pythagoreans emerged. Enthralled by the beauty and orderliness of arithmetical and geometrical constructions, they tried to deprive the number of its main advantage: the abstractness." Today, mathematics has become a theory of algorithms, and a return to metaphysics is required on a new level to explain the world. So, the question is asked: "But there is no unified mathematical theory on the origin of life. And why not? What is so special about mathematics as a generalized universal method for describing and solving all problems, that radically distinguishes it from those methods used by nature?" And the answer is given: "In all cases without exception, mathematics operates exclusively with artificial objects: numbers or some of their "substitutes" (symbols and/or codes). Nature "works" only with physical objects... In short, real physical objects being in physical contact with each other always manifest their inherent functionality related to their inherent physics, that is, to the physics of the Universe in which the interaction takes place" [5, pp. 24–25].

The problem raised by Krylov is quite delicate and belongs to sophisticated metamathematics. In practical terms, Krylov is right referring to the hidden axiom of mathematics: "For any mathematical transformations, the primitive objects of mathematical operations (numbers and codes) have only one abstract property that is to represent some quantities." However, it is commonly known that in Cantorian set theory being the qualitative theory of differential equations, numbers are secondary. This difference in approaches to mathematics occurs even in mathematical logic itself, if the works of the formalist Hilbert and his contemporary Gottlob Frege (predicate calculus) are compared. Syntactic thinking is characteristic of the Kolmogorov tradition as well as of the work "Algorithmic Theories of Everything" (2000) by Jürgen Schmidhuber cited by Krylov [12]. The physicosemantic approach is closer to us [1, p. 204]; and the same position is also shared by Krylov: "It is always possible to find objects whose description in 'Schmidhuber universes' turns out to be not only incomplete but completely inadequate" [5, p. 28]. On the other hand, any study, including that of technology, inevitably encounters problems of language and symbolism.

Here, the notion of functionality is used, but Krylov understands it unconventionally. In this case, attention is drawn to the object-oriented programming (OOP) paradigm and the "Object–Properties–Functionality" triad. A formula is written out [5, p. 30] stating the following: 1) an object can have several properties; 2) each property depends on the properties of other objects (and other properties of the object itself), while functionality is the functional relationship itself. Krylov warns: "It makes no sense to consider only functionality without related physical properties: it would be just a part of a long-standing branch of mathematics called 'the general theory of computable functions.'" Two levels of GFT are identified: simple level based on the "Object–Properties" dyad; and the more developed one considering the entire triad. Two types of formal TOs are also immediately identified: synthesis similar to addition, and decomposition, i.e., separation. It is noteworthy that Krylov also introduces the TO analysis coinciding in meaning with the Measurement and Attestation (M&A) TO introduced by us [1, p. 116]; this is expressed mathematically as $F_i(x) \rightarrow < x, \beta >$, where β stands for the desired characteristic (parameter) of object x. Also, the seemingly incorrect case when $\beta \in \{0, 1\}$ stands for the sign of absence or presence of an object as well as the general case of measurement as a comparison of the particular object form with a standard is considered.

The TO definition is given in [5, p. 35]: "Objects in FT may in fact be understood as everything to which its 'technological operations' can be applied, that is, operations affecting in some way the objects themselves or/and their properties, or/and their mutual arrangement." By analogy with the alphabet in mathematical logic, Krylov introduces "naturally," in his own words, basic elements or the base for technology. And after all, considering the history of microelectronics, this theoretical idea seemingly taken from a mathematical mind has been indeed embodied in a list of materials, structural elements (of electronic component base), and typical technological processes. At the same time, modern technologies are open to innovations; they evolve changing their own "axiomatics." An algebraic, in spirit, definition of formal technology as a set of base and operations on its elements and structures, i.e., obtained from the elements of the base of complex objects, is given in [5, p. 36]. Here, the analogy with the carrier and signature of an algebraic system may be easily seen.

Then, the notion of creative technology is introduced, which is excessive in our opinion, since any practical technology always creates something new, setting aside the copying technology being an exotic case for production (e.g., polymerase chain reaction or the analogy with image transfer in microelectronics). Creativity, it seems, should be correlated with "usefulness." In this case, Stanislaw Lem's thought about classifying technology as science may be recalled, and it may be said that there is no useless science in the most pragmatic meaning of the word "useful," since it is never known in advance what information on nature would be useful and, moreover, would be extremely important and necessary. On the other hand, the distinction between creative and non-creative technologies gives Krylov grounds to speak on self-replication of biological cells and on amplification of life forms during evolution (up to the emergence of intelligence) as well as to introduce the notion of "evolutionary technology" [5, p. 41]. When analyzing the sum of technologies and using the notion of conjugate points [1, p. 355], Krylov, like us, comes to the idea of evolution through the development and complication of the technology base, but in an alternative way using the notions of creativity and base.

Krylov draws attention to the fact that "the novelty of structures should be determined exclusively by means of technology itself." This idea seems profound and important for analyzing the inventive activity and innovations, i.e., project activity becomes subordinate to the production and technological one. In practice, the opposite is usually true; at first, the structure, and then only the production route is determined. In a broader sense, it would be better to move to the level of the production process rather than to that of the route [1, p. 31]. Eventually, not "what to do" but rather "how to do it" becomes the main thing. Only then, the novelty would get the right to exist. At the same time, the inseparable unity of technology and structure has been pointed out, and Krylov strengthens and singles out the second side of this unity based on algebraic considerations. As for self-replication, Krylov's thought refers to Codd's cellular automata and sufficiency of a low level of functionality determined by the number of possible local transition functions and/or the number of cell states.

By analogy with a function of several variables, Krylov introduces a formal-technological function (FT-scheme of synthesis) that results in a new object/structure. Here, the set of acceptable TO parameters is explicitly introduced; in our terminology, this is the *tekhne* of the TO level [1, p. 115]. In addition to the schemes of synthesis, the "fixed disintegration" operation similar in meaning to "dosing" in food technology is introduced. Mathematical definitions for a number of private types of TO are given. And it should be said here that the TO described by Krylov is rather equivalent to microoperations [1, p. 108].

The following theorem on "the efficiency of accumulated knowledge," i.e., on the possibility to number all TRs, is formulated. Krylov explains: "Any technology being a finite algorithmic system by definition (i.e., a system with a finite number of types of initial operation objects and a finite number of operations on objects themselves) can generate only a finite number of objects (syntheses or structures) for a finite number of stages." The theorem is true abstractly and mathematically only. Some operations change the properties of objects while the combination of such properties, even with a finite number of operations, may be infinite in practical terms. This implies a somewhat fantastic, in our opinion, idea of the constructor–analyzer representing a Turing machine connected to a technological unit. According to Krylov, the technology is complete when it is infinitely creative and the technology of its synthesis can be recovered from the product design. The recoverability is seemingly understood as existence with an accuracy of unambiguity, since, for example, a joint can be made by different technological welding methods (laser, electric, ionic, etc.) exclusive of various additives. Krylov considers the coincidence of the term with completeness in logic accidental, but it seems that the analogy is quite adequate, since a formula is provable when there is a chain of formulas linking it with axioms. Chapter 1 is concluded by several mathematized definitions and statements as well as by a summary figure showing subtypes of technologies [5, p. 68], (Fig. 2).

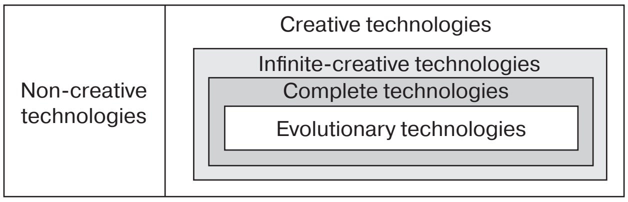

Fig. 2. Types of technologies selected by S.M. Krylov

CONTENT AND DISCUSSION OF CHAPTER 2

Chapter 2 deals with abstract notions of property and functionality, being rather difficult to understand; it invades the realm of philosophy, and is based on works by M. Bunge and E.M. Karpov. Krylov is aware of the complexity of the issue: "Interpreting the meaning of the term 'property' in each specific case in relation to each version of representation of systems, their components, and relations between components is one of the most complexities in studying systems... Referring to properties of individual objects and systems of objects, the fundamental difference in properties related to the dynamics of their behavior and in properties statically connected with objects themselves, that is those that allow distinguishing one object from another regardless of their dynamics, are not usually emphasized" [5, p. 74]. Krylov embarks upon the path of G. Klir and E.M. Karpov and gives the following definition: "A property of an object (element or structure) is its some numerical, geometrical, physical, or any other characteristic, including the imaginary one, remained steady under certain stable conditions, by which they (elements, structures) may differ from each other or from their state preceding in time and/or space."

Krylov emphasizes the technical meaning of this definition and rightly points out that "the presence of object properties may not necessarily imply the presence, among analytical operations, of the corresponding technology for operations directly determining the 'presence' or 'absence' of certain properties, and even 'measuring' their value" [5, p. 78]. Krylov also extends the predicative meaning of the property and writes openly that it is quite possible to display the property using an integer or finite real number, not only a Boolean number. It should be noted that this approach exists in the probability theory when a random event is compared with a random variable. According to Krylov, "in this notation, the possibility to limit the real (i.e., quite complete) list of object properties by its reduced version representing a full picture of their behavior in a particular context becomes quite obvious" [5, p. 80]. This problem of incompleteness is rather essential for practicing M&A TO of industrial technology and interpreting their results (in this regard, see our comments on the physical–statistical approach in the reliability theory [1, p. 233]). With regard to the importance of OOP, Krylov writes: "For us, the significant thing in this concept is its most important, central link, namely, that any object should be represented by a single set of parameters describing its features (properties!) as well as methods (techniques and functions) describing the use (interaction) of parameters inside and outside the object, i.e., with other objects. Indeed, any real object of the real world is not just a set of its static characteristics. It is also a process of its existence in the world around, its dynamics, and its evolution" [5, p. 81].

The object state is defined as a set of specific values of its properties and is interpreted as a vector in a multidimensional "space" (in our understanding, this space is analogous to the phase space in statistical physics). Noteworthy is the "method of assigned functionalities" consisting in decomposition of a property having multiple values into several properties with few ones, e.g., binary values [5, p. 83]. And, as Krylov rightly notes, this method is often used in designing cellular automata.

It should be repeated that the notion of "functionality" is introduced nonconventionally. In the GTT, functionality is the property of the final product to perform a useful function, but it may be undoubtedly possible to postulate the local functionality of the element of product or semi-finished product responding to external impact under some other given conditions in a "correct" manner, in the developer's view. Such a need does arise in microelectronics when characterizing basic structural elements, while the degree of "correctness" is fixed in the "Platform Development Kit." Krylov, though also mentioning external impact (through change), takes a different approach [5, p. 84]: "The property of an object (element or structure) is called functional when it allows changing the state of another object which this property of this object interacts with when these objects physically converge or connect." In our opinion, it would be more correct to speak of linking by introducing the abstraction "linkage," since it is hard to imagine physical convergence for information objects. Then, Krylov discusses the example of a *2AND–NOT* gate where its two inputs are called input properties while its output, i.e., the output property, becomes functional only when it is connected to another gate. However, functionality does exist without a connection, being specified by the truth table and its "correctness." Then, the operation of the four-component flip-flop is discussed in the language of functionality [5, p. 90]. As a more complex example, Krylov introduces the so-called "semistructured heterogeneous self-timed machine with individual object names" in the context of calculations using chemical reactions (in our opinion, a rather good example is given here by the Kirdin kinetic machine). Krylov refers to the Kauffman Boolean automaton being another network implementation.

Several statements on emergent properties concludes Chapter 2. Whereas the system-wide statement on emergence is considered in the GTT only in the sense that each level of technology description generates new specific concepts, Krylov links emergence with functionality in a more classical way. "An emergent property is the property of object x (with a non-empty value) been absent at previous steps of technology in those objects which object x is obtained from" [5, p. 100]. Here is an example of statements: "Statement 2.1. The property 'to have a given form' is emergent (in technologies, with dimensionality at least 2)." In our understanding, the dimensionality of the technology is identified with the number of properties of its final structure. For the von Neumann 29-state cellular automaton, two statements are formulated in the language of functionality. "Functionality" turns out to be a notion analogous to "method" in OOP. "Kinematic emergence" is the last notion introduced in Chapter 2.

CONTENT AND DISCUSSION OF CHAPTERS 3–5

Chapters 3–5 deal, on the one hand, with the development of the notions of "functionality" and "complexity" and, on the other hand, with physicochemical processes of prebiological and biological evolution. The property of self-replication is emergent when compared to organic molecules; this transition from the second to the third chapter is natural and subordinate to GFT logic. However, Chapter 3 begins with strange postulates for evolutionary technology: "There is 'space' and 'time'" [5, p. 111], with a reference to the everyday understanding (as far as we can see, this understanding corresponds to the Newtonian one). Statement 3.3 given on p. 102 is clearly physicalist, which reduces its generality but specifies and fixes Krylov's atomistics. Krylov's quasiatoms are analogous to atoms in chemistry having mass and inertia while their properties are quantized (Statement 3.4) to enable replication of base elements; samples of elements can be replenished from an external source. Perhaps, analogies with the works of Democritus are relevant here. The notions of "fields" and correspondingly of "forces" are of first importance: "More complex, nonlinear or nonmonotonic, or even alternating-sign versions of the functional dependence of the attractive force on the distance between elements are extremely difficult to analyze due to the infinitely large number of elements and the infinity of space itself" [5, p. 115].

Physicalism and even mechanicalism are also perceptible in the appearance of the inertia law in Statement 3.5. However, the following more general formulation would be interesting: "In order for the technology satisfying Statements 3.3–3.4 to be evolutionary, it is necessary that elements of the base have the property of preserving the properties ~~the direction of motion~~ in the absence of external forces (~~attractive and/or repulsive~~)." (*Krylov's text is crossed out while our one is underlined*). Constructing a type of forces, Krylov necessarily embarks on the path of molecular dynamics methods; to give concrete expression, we shall give an effective type, in Krylov's opinion, of the interaction force between two elements of the base:

$$F = \frac{K\left(d_{ij} - \left(r_i + r_j\right)\right)}{d_{ij}{}^n},$$

where i, j are element indexes, $r_{i,j}$ is their radii, d_{ij} is the distance between their centers, n is degree of interaction, and K is constant. For justification, Krylov refers to his own computer experiments demonstrating the presence of stable structures at $n = 3$ (which corresponds to the physics of our world) but refers only to one literature source published in 1997. It is noted that the introduction of the medium viscosity and heteropolarity of elements, i.e., the "charge" property, allows obtaining results that are more interesting. In our opinion, the book would have benefited has Krylov included a more detailed description beyond illustrations of lumping balls (Fig. 3). The summary is given on p. 121: "For example, ball-cells can be provided with a set of states and functionalities similar to those of von Neumann cellular self-replicating automata. This results in a structure wherein self-replication of structures may occur. Thus, for the first time we have approached the first formal–technological model of the 'universe' in which evolutionary (or rather, similar to them) technologies and processes are theoretically feasible."

Krylov is skeptical of the probability of self-replicating configurations as in the von Neumann automaton recording the following in the Statement 3.6: "The slightest inhomogeneity in the environment surrounding the automaton may result in a failure in the self-replicating process, and the later stops" [5, p. 122]. However, by equipping quasiatoms with the new "number of electrons" property resulting in an analogue of covalent bonding, Krylov has been able to obtain stable configurations preserving the structure under various collisions.

Chapter 4 begins with discussing the concept of entropy. We tend to agree with the following remark (p. 125, emphasis added): "... (*The conventional approach*) considers any system as already given, existing in nature, whether it is actually so or whether *it is created in a constructive manner* from some initial components. Hence the following paradox arises: as long as probabilities of appearing particular states of a system (i.e., its different 'configurations' in the broadest sense of the term) are unknown, nothing can be said either about the value of its entropy or about the nature of its possible changes under particular transformations (conversions) of the system." The redundancy of the Shannon formula for the amount of information in a message as well as the great simplicity chosen by nature in the genetic code (64 codons per 20 amino acids) and used by the developers of information systems are noted here.

Functional complexity as an all possible number of states of the system is introduced. Structural complexity, or structural functionality, is introduced first for linear structures understood through left-right relations. It is stated on p. 131 that eventually the minimum number of functional states providing "three-dimensional" structural completeness of linear structures (analogue is the curve in three-dimensional space) is equal to five. Then, one of the basic objects is selected to be called an automaton (in the GTT, it is the TO processor): "According to this scheme, the required minimum number of states of the synthesis automaton itself can be easily identified. It turns out to be small and equal to 12. That is, the (molecular) automaton ... capable of synthesizing linear structures may have only 12 functional states." As for any object-structure, the automaton functionality is introduced.

Krylov draws attention to the role of the energy factor underestimated, in his opinion, in Langton's works on artificial life. The scheme shown in Fig. 3 resembles the scheme of protein synthesis in ribosomes taken from some biology textbook. It should be noted that nature has really chosen linear structures, i.e., RNA molecules or protein primary sequences, but articulations of parts is more diverse in human engineering, not to mention the ways of association/connection in mental constructs.

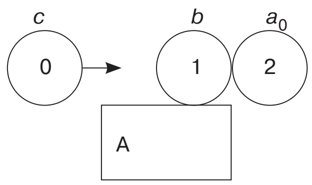

Fig. 3. Fragment of the schematic diagram for the random synthesis automaton A similar to the synthesis of a linear biopolymer. Circles show monomers, while the numbers in the circles are the values for the monomer states

The following four types of functionalities are listed on p. 135: dynamic (as the ability to move in space), structural (as the ability to articulate), logical (as the ability to control the assembly through the automaton), and energetic (introduced by Krylov vaguely). The first and the fourth types are closely related. Complementing the base with "automata–decomposition catalysts" makes the technology more productive. Krylov provides the results of computer simulation again but without a reference to the primary source. After appealing to the Kolmogorov complexity, the really fundamental *theorem on a fixed point of self-replication* is established (p. 145):

"Among linear technologies with the number of functional states per one base element greater than one, there are technologies in which the functional complexity of structures increases constantly with increasing length, whereas the functional complexity of the process (automaton) of their synthesis remains a constant value. Therefore, there are bound to be structures (or their combinations) whose functional complexity is equal to or even greater than the functional complexity of their synthesis procedure (automata) and, consequently, there are bound to be structures capable of replicating themselves."

In our GTT version, we postulate and even provide non-strict justification for the statement that the complexity of the product does not exceed the complexity of its production route (generalizing, of technological process). We confirm indirectly by this that the number of technological alternatives and variations [1, p. 115] may be very large as opposed to the finite number of structural versions. Thus, both statements come into intuitive contradiction, although expressed in different terms. There is no attempt to solve this contradiction here, but simply record it; discussing all nuances of correlation of "*tekhne*," "TR complexity," and hidden information in TO prescriptions would require more than one paper. In our opinion, the emergence of these contradictions in different GTT versions is fruitful and bears the impress of dialectics.

Chapter 4 ends with the description of more complex structures of automata enhanced by the possibility of complementarity (in order to "capture" DNA synthesis). The possibility of their combined action is close to Manfred Eigen concept of an hypercycle, and its features may be seen in our GTT as well; first, in the duality thesis [1, p. 107], and second, in the origin of Moore's law and scientific and technological progress [1, pp. 362, 373]. In our opinion, the idea of searching for ways of self-replication, despite its attractiveness, has had a somewhat detrimental effect on the development of science, only diverting intellectual forces from more achievable practical goals. Falling under the spell of this idea, Krylov continues trying to "attack self-replication" in Chapter 5 by introducing the concept of a partially self-replicating bio-like system (PSBS) along with two principles of Darwinian systems (mutation and selection). Three works by Eigen [13] translated into Russian in the 1970s have been apparently unnoticed by Krylov; otherwise, at least one of them would have been listed in references. While Eigen has used the apparatus of ordinary differential equations and nonlinear dynamics, Krylov is a vivid representative of the structural-algorithmic approach. The structural and functional features of the PSBS having a spatially distributed character, i.e., being intrinsically connectionist, are discussed on p. 173; the presence of control signals for activation and inhibition reinforces this analogy as well [14] (see Rumelhart's principles).

COMMENTS ON THE CONTENT AND DISCUSSION OF CHAPTERS 6–8

Chapter 6 begins with the following semi-definition: "Future technologies are, first of all, technologies integrated into multipurpose (ideally, extremely multifunctional, i.e., universal) automatically operating systems capable of solving a huge number of tasks without human intervention. Flexible automated manufacturing systems (FAMS) and, strange though it may seem, computers may be considered prototypes of such systems" [5, p. 178]. With regard to microelectronics, for example, it is seen how industrial technology is transformed into "high technology" [1, p. 262], which is associated with the transition to the so-called "Industry 4.0." Then, Krylov declares: "Based on the formal technological analysis, we shall try to develop some new basic model of the extremely multifunctional (universal) program-controlled device to perform any technological operations from a given set of operations F of some technology on any objects from the combined set A ∪ B of base elements and structures of the same technology." Then the problem of specifying a "universal technological system" arises. For solving it, Krylov informally uses the abstraction of the Turing machine, and the following definition appears: "It is natural to understand the universality of the system in any technology T = < A ∪ B, F > as the possibility to implement in it any sequence of any operations from F on any elements and structures from A ∪ B allowed for these operations including all possible results of analysis operations from F that can change further sequences of operations." In terms of the TO level, the analysis operations are control-measuring ones, and the GFT and GTT positions coincide here; however, further on the difference arises: for Krylov it is, first of all, controllability (the if... else conditional-branching test) while in the GTT, it is an element of *tekhne* at the production process level. A certain practical compromise here is the elimination of the defective semi-finished product from further technological process.

Then, the notion of "recursive scheme" similar to recursive function in the theory of algorithms is introduced in [5, p. 181]. "Storage cells" are introduced in a somewhat unsophisticated way, i.e., Krylov tries to turn to and transcend some computing model [5, p. 183]: "This assumes that all such (structures – *auth*.) are fairly uniform (i.e., homogeneous) objects that can be stored in single-type storage cells and moved by single-type transport routes." For conditions of the real production, the assumption of homogeneity seems rather shaky. It should be noted that the "computing model" is a relevant notion [15] from the computability theory requiring a separate analysis. Here, Krylov inserts some material and technical aspects. The very notion of a "storage cell" is used as a generalization of the memory cell in computer science; the difference between access by address and access by pointer in FAMS scheme is discussed (Fig. 6.2 in [5]). Krylov's logic is very much affected by the notion of assembly production or assembly "chemistry," but for us microelectronics serves as an example of a different, non-assembly technology. Krylov notes the following on p. 189: "To achieve 'algorithmic completeness', i.e., to create a sufficiently powerful information basis in various technologies equivalent to mathematics in its potential capabilities (and, therefore, providing a solution, among other things, to any problems related to controlling the universal technological system), the formal mechanism should not be that complicated. There should be at least 'something' that may be distinguished from 'nothing' along with the ability to locate this 'something' in right places of space (in right storage cells) in the right sequence so that this sequence could then be processed again."

In the final part of Chapter 6, Krylov turns to specific designs of schemes; here, the abstractness of presentation disappears giving way to Krylov's scientific specialization in the design of "systems-on-a-chip" as well as programmable logic integrated circuits and matrices. Although the general terminology is preserved, it is completely forgotten that an integrated circuit, first of all, converts a signal [1, p. 55] rather than something atomic and molecular. Thus, FAMS feasibility remains questionable, although for the GTT production process level, Krylov's idea seems rather interesting and, perhaps, relevant in terms of process flow. Separation of storage cells and process cells in the context of smart chemical synthesis [5, p. 216] corresponds, in our view, to the logic of the pharmaceutical and genetic engineering development while the idea of controlling demonstrates the great potential of chip synthesis with biotechnology. In this respect, the book seems extremely useful for developers of "labs-on-a-chip" and microsystem technics (Fig. 4) being an excellent example of descending from abstract algebraic abstractions to the real production, even though biopharmaceutical for now. On the other hand, we are skeptical of disseminating these ideas to other technologies.

Krylov also rightly notes that technology may not always create linear objects (Chapter 4) and turns to planar objects estimating the complexity of their synthesis on p. 225. Technological cells and Krylov's synthesis machine resemble in some way the cells of the cellular automaton but have a more complex internal structure inherited from the stored objects; there is also an analogy in the synthesis results (e.g., by S.M. Achasova [16]).

Chapter 7 deals with adaptation of Church's thesis for technological systems. The question is formulated as follows (p. 235): "What are the effective applicability limits of the computing technology operating with natural and rational numbers (i.e., the technology of partial recursive functions) in comparison with more complex technologies operating with objects of the real physical world?" The subordinate character of mathematics is noted once again (p. 240): "Mathematics is a tektology of neutral complexes (in Bogdanov's understanding, complex is something very close to the notion of structure in FT)." The notions of "partially unknown technology" and "complexity threshold" are introduced. The proofs of 10 statements presented in Chapter 7 seem not to be rigorous enough.

In chapter 8, Krylov attempts expanding the GFT to cover social systems, and the intertwined nature of

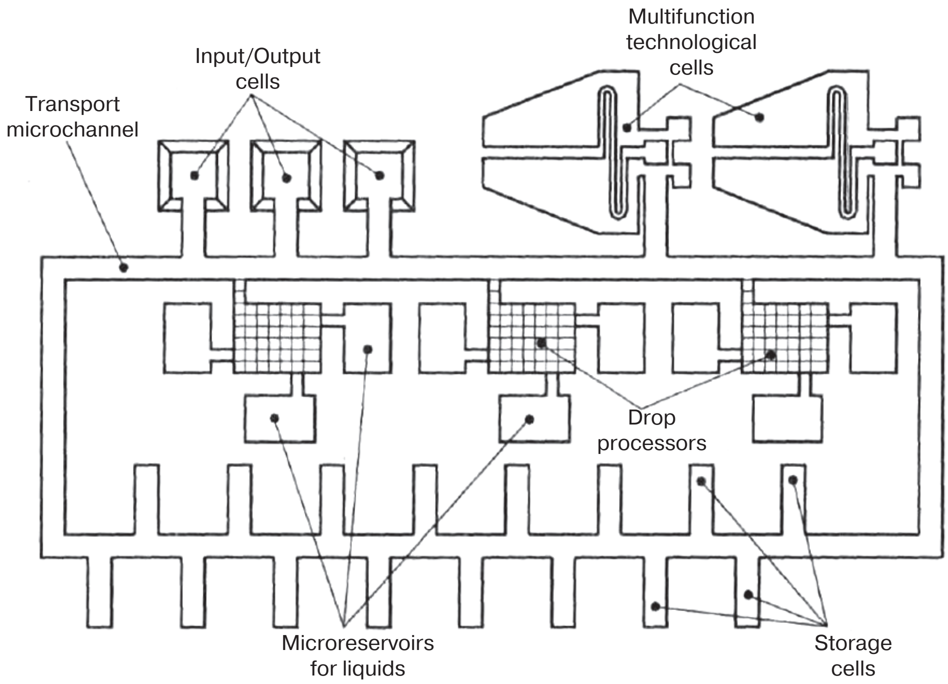

Fig. 4. Topography of the hypothetical nanofactory-on-chip having recursive structure and containing three microobject Input/Output devices (Fig. 6.13 in [5])

personality traits that cannot always be separated along parameter axes is pointed out on p. 252. Recognizing the complexity of the problems, Krylov in his inexact reasoning relies on the model for implementing the shortest path of evolutionary development discussed in Section 5.1 as well as on the Kolmogorov complexity criterion of the multicomponent object (in FT interpretation) discussed in Chapter 4. The above views cannot avoid comments.

As rightly pointed out in Neocybernetics, "the main ('basic') component of various social, industrial and other groups of people is the human being (the individual)." While the natural and social sciences study nature and society, technologies create the human environment. According to P.K. Engel'meier [17], "...technology is a part of the social history of mankind inextricably linked to nature. Through technology man transforms the environment adapting it to his needs." The manufacturing or social technology cannot develop without human activity. Technology (so far, at least) is not manless; it is a unitary whole only when "augmented by humanity," and this is where the difference, maybe the most significant one, lies, since bioevolution is undoubtedly a non-moral process, which is not the case of technological evolution. Technology is not a separate part of the process. Someone or something implements it. This is an indispensable condition for its existence. Without this, it is dead.

Reasoning about the impact of climate on the development of social structures and, especially, on the development of technology including currently are highly subjective. On the other hand, according to the classics of dialectics, "if man, by dint of his knowledge and inventive genius, has subdued the forces of nature, the latter avenge themselves upon him by subjecting him, in so far as he employs them, to a veritable despotism independent of all social organization" [18]. Krylov writes on p. 258: "The most important 'internal' mutagenic factor determining the possible rate of evolutionary development of a given society is 'the degree of permitted free action of certain social subsystems.' Simply stated, this is the degree of 'inner freedom' of a given society. If the level of this freedom is low, i.e., the system is rather rigidly organized (e.g., 'totalitarian'), then, obviously, the rate of evolution of such system would be minimum, and it would inevitably lag behind in its development compared with its more 'internally free' neighbors. This, in turn, would result in the loss of efficiency as well as in losing the competitive struggle." These conclusions are unsupported. In contrast, technological breakthroughs of the thirties in Germany and in the USSR should be noted. These countries are considered totalitarian regimes. In addition, what about the pace of technological advance in China today? The concept of the Megamachine proposed by L. Mumford may be also referred to.

Krylov reveals the difference between a technocratic organization and a democratic one: "In the first case, restraints are developed by the ruling elite while in the second one they are the product of the social group activities and citizens interested in them." The United States is a technocratic society despite its advanced democracy. Democratic France pursues the same path [19]. If only...democracy in form ceases to be democracy in substance.

It is stated on p. 262: "The tragic mistake of the founders of Marxism was to accept the most unfortunate result of the development of social systems as the norm, as the 'driving force of history,' even though the social systems existed at that time deserved their fate," and then on p. 263: "...therefore, it would hardly make sense to deny nature its 'reasonableness.' It is simply a reason of a different plane, different organization, and different destination than our own reason being the product of the former's activity furthermore." Then, Krylov pursues Vernadsky's ideas of the noosphere: "All types of reasons are capable of solving (creatively! – i.e., with creation of new 'inventions') various problems, including those they face unexpectedly. In case, of course, these tasks are fundamentally solvable within the resources and technologies that are available to these reasons at the current stage of development."

In the context of the fourth industrial revolution, the Marxist view of the driving force of history that is primarily the technology development acquires even greater relevance, but at the same time, Engels's warning [20] should not be overlooked: "Let us not, however, flatter ourselves overmuch on account of our human victories over nature. For each such victory nature takes its revenge on us. Each victory, it is true, in the first place brings about the results we expected, but in the second and third places it has quite different, unforeseen effects which only too often cancel the first." We would like to pursue Krylov's thoughts on beauty and social reason [5, pp. 264–265] and tell the ideologists of revolutions (Klaus Schwab) that the world is more complicated than they think, and its self-organization should be trusted. Apparently, this is why Krylov has made critical remarks addressing Marxism, although the debate over the essence of true Marxism is still continuing [21].

CONCLUSIONS

We hope that in the summary review form, we have managed to encourage the reader becoming directly acquainted with the books by S.M. Krylov. It should be noted that the monograph [6] is publicly available. Comparing both GTT and GFT theories (however, they are rather still sketches being far away from the status of a real "theory"), the first one is more general in terms of objects of consideration and may include GFT at three levels of six: technological operation, technological route, and technological process. In matters relating to the complexity measure and entropy, GFT has advanced further demonstrating an interesting approach inspired by algorithmic and atomic assembly processes of molecular "living" structures, but anyway, many issues are still far from being solved. In our book [1], Krylov's works have not escaped our attention, but we have focused less on them than they deserve.

Nevertheless, the book may encourage a fundamental view of science—from arithmetic to quantum physics—as opposed to the informational "pills" often used in teaching to "improve" education. These "improvements" ensuring seemingly immediate success and favoring technological "production" of personality structures suitable for society (and who is so brave as to define the criteria of suitability?) may result eventually in the destruction of that education awakening the desire to compete and overcome obstacles.

The immediate success of such "improvements" overshadows further harms, which they are paid for with. The richer society is, the more obviously it embarks on this path. Who knows whether "synthetic obstacles" would ever begin to be implemented so that they return value to pursuing goals that are excessively facilitated?

In our opinion, the excessive regulation of educational goals and content by the state is an inevitable process, especially during the technology transition to the industrial stage [1] of its development. At the same time, this is a negative process reducing the diversity of personalities whose structures are formed through upbringing and education. Exactly in Krylov's book, general formally algebraic principles of formation including mental-psychological constructs are given. Eliminating the possibility of self-organization, manifestation of human freedom, and the chaos inherent, albeit to a small extent, in nature, the social development path variability is eventually reduced. Contemporary philosophers note the chaos aspect: "From a traditionalist (deterministic) society we are moving to a stochastic (technological) one" [22].

Authors' contribution. All authors equally contributed to the research work.

REFERENCES

1. Krasnikov G.Ya., Gornev E.S., Matyushkin I.V. *Obshchaya teoriya tekhnologii i mikroelektronika* (*General theory of technology and microelectronics*). Moscow: TEKhNOSFERA; 2020. 434 p. (in Russ.). ISBN 978-5-94836-611-1. Available from URL: https://www.technosphera.ru/lib/book/656
2. Krylov S.M. Formally-technological models in the general systems theory. *Izvestiya Samarskogo nauchnogo tsentra Rossiiskoi akademii nauk = Izvestia of Samara Scientific Center of the Russian Academy of Sciences*. 2003;5(1):83–90 (in Russ.).
3. Krylov S.M. *Theory and methods of development of multifunctional programmable technological systems based on formal technological analysis*. Thesis. Samara; 2005. 451 p. (in Russ.).
4. Krylov S.M. *Formal'naya tekhnologiya i evolyutsiya* (*Formal technology and evolution*). Samara: SamGTU; 2012. 325 p. (in Russ.). ISBN 978-5-7964-1547-4
5. Krylov S.M. *Neokibernetika: algoritmy, matematika evolyutsii i tekhnologii budushchego* (*Neocybernetics: algorithms, mathematics of evolution, and future technologies*). Moscow: URSS; 2008. 288 p. (in Russ.). ISBN 978-5-382-00651-2
6. Krylov S.M. *Metamatematicheskie osnovy nauki budushchego: monografiya* (*Metamathematical foundations of the science of the future: monograph*). Samara: SamGTU; 2014. 247 p. (in Russ.). ISBN 978-5-7964-1686-0
7. Verzilin D.N., Sokolov B.V., Yusupov R.M. Neocybernetics: state of research and development prospects. In: *"Sistemnyi analiz v proektirovanii i upravlenii": sb. nauchnykh trudov XXIII Mezhdunar. nauch.-praktich. konf.* (*System analysis in design and management. Collection of scientific papers XXIII Intern. scientific and practical conf.*) V. 1. St. Petersburg: Politekh-press; 2019, p. 81–98 (in Russ.).
8. Mendeleev D.I. Tekhnologiya. In: *Sochineniya. T. XXI. Ekonomicheskie raboty* (Technology. In: *Writings. V. XXI. Economic works)*. Leningrad – Moscow: Izdatel'stvo Akademii nauk SSSR; 1952. P. 333.
9. Bogdanov A.A. *Tektologiya: vseobshchaya organizatsionnaya nauka*: *v 2-kh kn*. (*Tectology: general organizational science*: *in 2 v.*) Moscow: Ekonomika; 1989. V. 1. 304 p. (in Russ.).
10. Engel's F. *Anti-Dyuring*. In: Marks K., Engel's F. *Polnoe sobranie sochinenii* (Engels F. *Anti-Dühring*. In: Marx K., Engels F. *Full composition of writings*). Moscow: Gospolitizdat; 1961. V. 20. P. 11. (in Russ.).
11. Ivlev A.A., Artemenko V.B. Ontology of military technologies: bases, structure, visualisation and application. *Vooruzhenie i Ekonomika = Armament and Economics*. 2011;4(16):35–52 (in Russ.). http://www.viek.ru/16/35-52.pdf
12. Schmidhuber J. Algorithmic Theories of Everything. https://arxiv.org/abs/quant-ph/0011122
13. Eigen M., Shuster P. *Gipertsikl. Printsipy organizatsii makromolekul* (*Hypercycle. Principles of the organization of macromolecules*). Moscow: Mir; 1982. 270 p. (in Russ.).

СПИСОК ЛИТЕРАТУРЫ

1. Красников Г.Я., Горнев Е.С., Матюшкин И.В. *Общая теория технологий и микроэлектроника*. М.: ТЕХНОСФЕРА; 2020. 434 с. ISBN 978-5-94836-611-1. URL: https://www.technosphera.ru/lib/book/656
2. Крылов С.М. Формально-технологические модели в общей теории систем. *Известия Самарского научного центра Российской академии наук*. 2003;5(1):83–90.
3. Крылов С.М. *Теория и методы разработки многофункциональных программируемых технологических систем на основе формально-технологического анализа*: дис. … докт. техн. наук. Самара; 2005. 451 с.
4. Крылов С.М. *Формальная технология и эволюция*. Самара: Самарский гос. технический ун-т; 2012. 325 с. ISBN 978-5-7964-1547-4
5. Крылов С.М. *Неокибернетика: алгоритмы, математика эволюции и технологии будущего*. М.: URSS; 2008. 288 с. ISBN 978-5-382-00651-2
6. Крылов С.М. *Метаматематические основы науки будущего: монография*. Самара: Самарский гос. технический ун-т; 2014. 247 с. ISBN 978-5-7964-1686-0
7. Верзилин Д.Н., Соколов Б.В., Юсупов Р.М. Неокибернетика: состояние исследований и перспективы развития. В сб.: «*Системный анализ в проектировании и управлении»: сб. научных трудов XXIII Междунар. науч.-практич. конф.* Ч. 1. СПб.: Политех-Пресс; 2019. С. 81–98.
8. Менделеев Д.И. Технология. В кн.: *Сочинения.* Т. XXI. Экономические работы. Л.-М.: Изд. АН СССР; 1952. С. 333.
9. Богданов А.А. *Тектология: всеобщая организационная наука*: *в 2-х кн.* Абалкин Л.И. (отв. ред.). М.: Экономика; 1989. Кн. 1. 304 с.
10. Энгельс Ф. Анти-Дюринг. В кн.: Маркс К., Энгельс Ф. *Полное собрание сочинений*. Т. 20. М.: Госполитиздат; 1961. С. 11.
11. Ивлев А.А., Артеменко В.Б. Онтология военных технологий: основы, структура, визуализация и применение. Ч. 1. *Вооружение и Экономика*. 2011;4(16):35–52. http://www.viek.ru/16/35-52.pdf
12. Schmidhuber J. *Algorithmic Theories of Everything*. https://arxiv.org/abs/quant-ph/0011122
13. Эйген М., Шустер П. *Гиперцикл. Принципы организации макромолекул*: пер. с англ.; под ред. Волькенштейна М.В., Чернавского Д.С. М.: Мир; 1982. 270 с.
14. Rumelhart D., McClelland J. *Parallel Distributed Processing.* V. 1. Explorations in the Microstructure of Cognition: Foundations. PDP Research Group (Eds.). MIT Press, Cambridge, MA; 1986. ISBN 0-262-63113-X
15. Матюшкин И.В. Коннекционистское расширение минимальной модели вычислений (Часть 1). *Философские проблемы информационных технологий и киберпространства*. 2016;1(11):103–120. https://doi.org/10.17726/philIT.2016.11.1.004.27
16. Ачасова С.М. Клеточно-автоматная самовоспроизводящаяся матрица из искусственных биологических клеток. *Проблемы информатики*. 2016;3(32):13–25.
17. Энгельмейер П.К. Творчество в технике. В кн.: *Философия техники*. Вып. 1. СПб.: Военмех; 2006. С. 150–185.

[Eigen M., Schuster P. *The Hypercycle. A Principles of Natural Self-Organization.* Berlin, Heidelberg, NY: Springer; 1979]
14. Rumelhart D., McClelland J. *Parallel Distributed Processing.* V. 1. Explorations in the Microstructure of Cognition: Foundations. PDP Research Group (Eds.). MIT Press, Cambridge, MA; 1986. ISBN 0-262-63113-X
15. Matyushkin I.V. Connectionist extension of irreducible computation model (Part 1). *Filosofskie problemy informatsionnykh tekhnologii i kiberprostranstva = Philosophical Problems of Information Technology and Cyberspace*. 2016;1(11):103–120 (in Russ.). https://doi.org/10.17726/philIT.2016.11.1.004.27
16. Achasova S.M. Cellular automata self-replicating matrix of artificial biological cells. *Problemy informatiki = Problems of Informatics*. 2016;3(32):13–25 (in Russ.).
17. Engel'meier P.K. Creativity in technology. In: *Filosofiya tekhniki* (*Philosophy of technology*). St. Petersburg: Voenmekh; 2006. V. 1. P. 150–185. (in Russ.).
18. Engel's F. About authority. In: Marx K., Engels F. *Polnoe sobranie sochinenii* (*Full composition of writings*). Moscow: Gospolitizdat; 1961. V. 18. P. 11. (in Russ.).
19. Gelbreit D.K. *Novoe industrial'noe obshchestvo* (*New industrial society*). Moscow: AST; 2004. 602 p. (in Russ.). ISBN 5-17-024777-X
[Galbraith J.K. *The New Industrial State*. Princeton University Press; 1985. 520 p.]
20. Engel's F. Dialectics of nature. In: Marx K., Engels F. *Polnoe sobranie sochinenii* (*Full composition of writings*). Moscow: Gospolitizdat; 1961. V. 20. P. 495–499. (in Russ.).
21. Penzin A., Podoroga V., Chukhrov K. Marx against Marxism, Marxism against Marx. *Stasis*. 2017;5(2):530–552 (in Russ.). https://doi.org/10.33280/2310-3817-2017-5-2-266-288
22. Budanov V.G., Arshinov V.I., Filatova O.E., Popov Yu.M. Third paradigm and laws of development of societies. *Slozhnost'. Razum. Postneklassika = Complexity. Mind. Postnonclassic*. 2020;1:38–45 (in Russ.). https://doi.org/10.12737/2306-174X-2020-37-44

18. Энгельс Ф. Об авторитете. В кн.: Маркс К., Энгельс Ф. *Полное собрание сочинений*. М.: Госполитиздат; 1961. Т. 18. С. 303.
19. Гэлбрейт Д.К. *Новое индустриальное общество*: пер. с англ. М.: АСТ; 2004. 602 с. ISBN 5-17-024777-X
20. Энгельс Ф. Диалектика природы. В кн.: Маркс К., Энгельс Ф. *Полное собрание сочинений*. М.: Госполитиздат; 1961. Т. 20. С. 495–499.
21. Пензин А., Подорога В., Чухров К. Маркс против марксизма, марксизм против Маркса. *Стасис*. 2017;5(2):530–552. https://doi.org/10.33280/2310-3817-2017-5-2-266-288
22. Буданов В.Г., Аршинов В.И., Филатова О.Е., Попов Ю.М. Третья парадигма и законы развития социума. *Сложность. Разум. Постнеклассика*. 2020;1:38–45. https://doi.org/10.12737/2306-174X-2020-37-44

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