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To the Justification of the Effectiveness of Future Mathematics in the New Biology

M. A. Guzev[*,1] **and Yu. N. Zhuravlev**[**,2]

[*] *Institute for Applied Mathematics, Far Eastern Branch of the Russian Academy of Sciences, 690041, Vladivostok, Russia*
[**] *Federal Scientific Center of Biodiversity, Far Eastern Branch of the Russian Academy of Sciences, 690022, Vladivostok, Russia*
E-mail: [1]guzev@iam.dvo.ru, [2]zhuravlev@biosoil.ru

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Abstract — A list of selected phenomena characterizing living systems on the main levels of the manifestation of life is considered. As a result of directed interpretation of these phenomena, life (in becomming of earthly reality) appears as an informational physico-mathematical process that solves the problem of optimal relations of its variability and heredity in a changing environment. Practical solutions found by living systems in the course of evolution can be used and are used in applied mathematics as approaches of working with information. Genetic and quantum algorithms, neural networks, annealing are important milestones of this use. On this way, mathematics discovers an unexpected efficiency in working with big data arrays, which represent the main content of modern biology.

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1. INTRODUCTION

Wigner [1] wrote about unreasonable, exceeding the expectations, effectiveness of mathematics in natural sciences, presenting the image of "a man with a bunch of keys, who, trying to open one door after another, always finds the right key on the first or second try. This makes him to doubt about a one-to-one correspondence between keys and locks." Arnold [2] attributed to I. Gelfand, as if he had added that there is another comparable phenomenon, namely, an equally incomprehensible inefficiency of mathematics in biology. If this is the case, then the inefficiency in biology makes one to doubt at least about some correspondence between keys and locks: either the keys or the locks are wrong.

Wigner gave his lecture more than half a century ago. Arnold shared these beliefs a quarter of a century later, not paying attention to the fact that biology and mathematics are already then became different.

Much has changed since then.

Biologists have learned to sequence and edit genomes, huge databases of genes, mutations, and interactions have occurred. The time has come for the synthesis of vital sequences. A new mathematics has come into the new biology, which (forestalling Plushkins) does not cancel traditional directions at all, although new ideas, for example, the unification of sciences, can seem untenable from the standpoint of classical mathematics. The novelty of biology lies in its increasing approaching to the representations of the microcosm, in its ever greater saturation with physics, mathematics, and computer science. The phenomena of biology are increasingly attracting matrix mechanics for their descriptions. Has not yet taken shape as a discipline, the photonics of living systems already exists in many manifestations. Neurobiology, the science about the most secret process of the brain, suddenly received its physical and mathematical interpretation. And there is no longer any doubt what shall be the qualitative response to Davis' question: "Does quantum mechanics play a non-trivial role in life?" [3].

The novelty of mathematics, complementary to these biological advances, is that the first principles of biology began to be used to create mathematical models in various areas of human practice. Our appeal to the first principles of biology differs from the typical one, but it is similar to Fock's appeal to occupation numbers [4] and Maslov's constructions, which he used in the proof of a general theorem of set theory [5]. Justifying the predictions of S. Ulam, mathematicians were imbued with the ideas of unification [6, 7, 8] and began to use schemes of solutions found by biological evolution for solving applied problems. The work began with genetic algorithms and received a brilliant continuation in using neural networks. Next in line are Big Data technologies, anticipatory systems, and quantum algorithms. Ideas about tropical mathematics produced a revolution in some areas of the economy. The further building of bridges between sciences is possible on the way of generalizing the classifying topos of Grothendieck [9] and using univalent foundations of mathematics as standard tools [10]. Finally, we must remember that even Edwin T. Jaynes claimed that there is a fundamental connection between the theories of information, quantum mechanics, and statistical thermodynamics [11]. Jaynes is often credited with the fact that as a result of his work, the concept of entropy, as a central representation of thermodynamics, went beyond the limits of physics and turned out to be applicable in biology. In the most general sense, this is true, but, from a position that studies becoming, it is more important to study what happens in the very space of becoming, and not what remains outside it. Therefore, we shall talk more about the connection of information theory, quantum mechanics and biological evolution.

In this paper, we intend to explore whether there is a possibility of such an unification of mathematics and biology, a unification in which the bridges connecting them shall be found. We are interested in the following questions: are there levels of knowledge at which, speaking in Wigner's words, there is a mutual correspondence between the phenomena of biology and axioms of mathematics, and, if so, where are they and to what stage the formation of living reality they could correspond?

To achieve this goal, we are first to establish what phenomena in biology should be considered fundamental from a new (our) point of view and how they are related to the fundamental principles of physics, where mathematics is effective. It is possible that, when using such an approach, new relations between the living and the inanimate shall open up, and new assumptions about the time, place and depth of their bifurcations in the course of the formation of our reality shall become available.

2. PHENOMENA OF PHYSICS AND BIOLOGY AS THE FIRST PRINCIPLES OF LIFE

In this work, we shall use the term "phenomenon" as is customary in natural sciences, i.e., to designate with it an observed phenomenon or event, doing it for the first time without considering the reasons. We shall select, from the immense multitude of biological phenomena, only those that, in our opinion, are inseparable from the nature of living things and the absence of which in models of living systems can be the reason of the inefficiency of mathematics in biology.

Since the world known on Earth is represented by both living and nonliving systems, it is natural to expect that, among the first principles of becoming, one can discover both principles common for living and nonliving systems and those that separate them. For the completeness of the model of life, it is important to take into account both of them.

2.1. General Physical Phenomena

2.1.1. Existence. For the first and most important phenomenon of life, we consider the fact that it exists. It exists as a miracle in the terminology of Misha Gromov, who considers as a miracle any phenomenon which we cannot model and understand [12]. To construct a model means to understand, says Gromov. Or to fool ourselves, adds Arnold, if the facts known "only with some degree of probability or only with some certainty" are taken for axioms [2]. Therefore, it is important to understand that "life" exists *in* and *equally* with the inanimate *nature* that surrounds us, without giving us much reason to think as if one came from the other.

The form of existence of living objects is both similar and different from the form of existence of inanimate objects [13]. Thus, not all inanimate nature is represented by bodies as beings that have precisely a shape, while all life known to us is represented by organisms with a characteristic shape: organisms of the same species are similar to each other, but clearly differ from organisms of another species. In the simplest life forms, such as viruses, mycoplasmas, and mini-bacteria, some signs of organisms may be absent, more precisely, they may be functionally replaced. One can trace a higher supra-organismal form of organization, which participates in the evolution of the living and is absent in the formation of non-living systems. The fact of preservation of important spatial characteristics of isolated objects can indicate the possibility of co-evolution of objects and environment, but this side of the matter still waits for its information coverage.

2.1.2. Dynamics of Existence. All living things, like all things, are characterized by the dynamics of existence [14]. But there are differences.

Organisms exist in a state of dynamic disequilibrium with their environment, representing open systems, because without the opening of the system its evolution is impossible [15]. The incomplete locality of organisms (system openness, pseudo-locality) and their incomplete isolation from the environment is related to the fact of their existence in such a state. Organisms make an impression of isolated (closed) systems, but retain the most direct communication with the environment, passing through themselves the flows of matter, energy, and information. This gives reason to call them the clopen systems. This term suggests that, at some time and in some respect, the system is open and, at another time and in another relation, it is closed.

An important consequence of incomplete isolation is that living organisms cannot exist outside the environment, the local organization of which they are.

The incomplete isolation underlies the co-evolution of the living and its environment. This is especially evident in our time, when the artification of the Earth and its near space reached alarming levels. Then the content of co-evolution, on the one hand, there will be development, internalization by allocated objects of those functions of the environment that, at the beginning of their formation, ensured their isolation, and subsequently their existence. On the other hand, the content of co-evolution depends more and more on the return to the environment of life-transformed flows of matter, energy, and information, which is its artification.

2.1.3. A special state of existence: excitation. Common to living and nonliving systems is their ability to excite, perturbation, at the beginning of which lies the interaction of the system with something from the outside, which has the characteristics of energy, matter, or information. Further, for brevity, let us talk about energy.

The fact of commonality in the ability to excite should not prevent us from considering excitation as a fundamental property of living systems. The excitation as physical phenomenon is characterized by the perturbed energy state of the system, it is the form and mode of energy flow through the system, and therefore can be regarded to be fundamental for any system. The inclusion of excitation in the list of the first principles of life is necessary, since a perturbation, applied to a closed system, opens the closed system, passing a flow of energy through it. A perturbation applied to an open system affects its energy balance and can change both the amount of energy in the system and its direction of use.

Closed inanimate objects also open when excited, but their capabilities for the use of the added energy is very limited. If they use excitation energy for the formation of chemical bonds, then the reactions go up to a formation of inert compounds, and the further evolutionary dynamics is strongly slowed down or is impossible. An inanimate object that has entered into a chemical reaction may cease to be "himself." If the energy in an inanimate object is not stored, then its dissipation occurs, which is useless for evolution. After the dissipation of the excitation energy, such systems close again.

In modern organisms, the excitation energy is stored in various forms of chemical bond, mainly in the macroergic phosphate bond, and can be stored or used in many ways [13]. The main directions are the work of the organism on the complication of "itself" and the work on interaction with the environment.

The first direction has the specific feature that, by "complicating themselves," organisms remain "themselves," while the complication, for example, of a molecule or a complex of molecules leads to the formation of a new substance.

The second direction is especially important when it takes the kinetic form (movements). If the dynamics of the environment is assessed as changes in the landscape of favorable conditions for living systems, then, for "the survival of the fittest" (Darwin), the decisive factor is movement as a condition of entering the favored zone. Starting with the particles of the quantum world, excitation changes the dynamics of their movement [16]. In living systems or their predecessors, due to changes in directions and speed, the probability of falling into the favored zone can increase. The occurrence of molecular flagella in bacteria increases and modifies movement parameters, which can be understood as an increase in the number of tests of environmental zones for favored, and the organisms on fitness.

In multicellular organisms, phenotypic structures occur that can provide directional movement, and the success of survival is dependent on the selected motion vector. If the system itself chooses a vector, this can mean that it has become anticipatory (according to Rosen [17]), and its behavior refers to biological phenomena.

Thus, the excitation has common initial characteristics. However, for the nonliving systems, it leads to the dissipation and closure of the system, or to a deeper change leading to the loss of individuality. Whereas the excitement of a life-like system is accompanied by the storage of excitation energy and preservation of individuality with complication and beneficial use of energy excitement in the evolution.

The reasoning about excitation as a state that distinguishes between living and nonliving systems leads to the conclusion that the formation of living systems is associated with their thermodynamic opening and useful (according to Brillouin [18]) work, and that of inanimate ones with their closure after dissipation. This is important for choosing a modelling strategy in the study of the origin of life. The Miller era, for example, is largely aimed at searching for the closure of natural chemical cycles, and this is the source of the difficulties and contradictions in the theory of abiogenesis, the main of which was formulated by S. Kauffman: "People have made self-reproducing molecular systems and molecular motors, but nobody's ever put the two together into a single system that is capable of both reproduction and doing a work cycle" [19]. Theories/models of the origin of life as the formation of systems oriented on opening due to exitement are not known for us, and this may be the reason for the inefficiency of mathematical models of life, although in the theory of open systems there are all prerequisites to create effective models [20, 21].

2.2. Biological Phenomena

2.2.1. Program and Mapping in the Genotype/Phenotype Bilayer. Organisms, especially macroscopic ones, are characterized by individuality, growth, and development that make up ontogeny, which is the sequence of events from birth to death [22]. Being born, organisms change every moment of their existence at the expense of exchange with the environment and grow and, nevertheless, retain their individuality. They also die individually.

In the most general framework, a similar cycle of transformations can be regarded as a fundamental. property of bodies that have a shape; it is inherent not only in living bodies, but also in quantum particles, molecules, and celestial bodies. They are often referred to as characteristic of living objects: birth, life and death. For example, a Lovelock's theory known claiming that the Earth is a self-regulating superorganism [23]. Heavenly bodies, like many other inanimate ones, are characterized by an exchange with the environment; in some respect, they can open up during a disturbance and can collapse, having exhausted their resources, which in some sense is equivalent to death. However, a significant part of inanimate nature is not framed into a body and cannot be described in terms of a reduced ontogeny.

The fact important for distinguishing "ontogenesis" of living and nonliving objects is that the first is carried out not randomly, but according to a program during which there is an embodiment of the genetic symbolic information (genotype) in material structures (phenotype). As a result, a bimodal organism is formed, which is able to re-create itself (autocatalysis) and present itself in the environment (interaction). The genetic information is passed on to offspring in symbolic form of a *sequence* of nitrogenous bases in DNA. The coding meaning of the sequence opens when reading the sequence of bases as a sequence of triplets that are molecular groups which are 3-permutations of four. The reading is carried out in two stages, which are called transcriptions and translations. The latter involves a supramolecular complex, the ribosome, in whose body the sequence of triplets is matched with the sequence of amino acid residues in the synthesized polypeptide [24]. The polypeptides, in their active configuration, are called enzymes and serve as the main operators of autocatalysis and interaction with the environment.

The layer of existence of individual information in a symbolic form in the "ontogenesis" of lifeless bodies is absent. These bodies have no genotype/phenotype distinction.

The presence of two layers (information and material) and a function of mapping between them is a feature of ontogeny that distinguishes the living from inanimate. Particularly noteworthy is the operation of mapping from layer to layer, requiring a special form of the operator as a many-placed function, as well as the operation of interaction with the environment. The evolution of a living object includes the evolution of the program, the evolution of the embodiment operator, the phenotype evolution, and the co-evolution of the object and the environment. If the mathematical model does not take this into account, it will be ineffective in describing life.

2.2.2. Generating Information. Thanks to Shannon [25], we know that an information can be copied, transmitted, accumulated, and transformed. The information responsible for the creation of a phenotype does not fall under this classification; it is more correctly attributed to the class of generating information, with the help of which, over a symbolic representation, a completely material layer of the phenotype is constructed.

In addition to the "descending" information from DNA to RNA and further to protein (Central Dogma of molecular biology), to create a phenotypically presented object, the dynamics of DNA architecture in chromatin and the dynamics of tubulin and membrane devices are important [24], which justifies Virchow's thesis ⟨omnis cellula e cellula⟩. Now we know that the genotype does not turn into a phenotype, it only triggers and directs the processes by which the phenotype is created by means of the organism itself, which speaks of the autocatalytic nature of living systems.

A part of autocatalysis mechanisms (e.g., epigenetic regulators, Yamanaki quartet, endoplasmic reticulum) goes to the offspring from the parents, and a part is created anew, creating together a certain "innate component" in the terminology of Chomsky [26], or a preorganization in the language of ideas about order, formulated already by Cram [27]. It is this very "innate component" that provides copying of DNA in the cell cycle, transfer of DNA and other hereditary information in the cell division, and the interaction of information from different sources in the layer mapping when creating a phenotype. These structures, for example, the cell membrane, may not be symbolic carriers of information, and it is often more correct to think of them as constraints of the information flow, but they evolve in the composition of the organism, providing an increase in its complexity. For the occurrence of constraints, flows are needed and, in this sense, we can assume that the information and its flows give rise to a living object in its multilateral representation.

The evolutionary complexity is created in such a way that every next layer of becoming covers the previous one, but does not reject it, and uses it as a basis. Chomsky showed such a formation on the example of grammar, and then became insist on its universality [26]. And the number of such layers/bases in the device of living reality becomes more and more as the formation of this reality continues, which corresponds to the layer-by-layer increase in knowledge in Wigner [1].

To be effective in describing life, a model must be oriented towards dynamical repetition of dual states such as excitement/rest, closing/opening and others that provide a fundamental property living systems, i.e., heredity and variability.

2.2.3. Reproduction of Organisms and Populations. The reproduction in general, i.e., as a continuously ongoing process of renewal, can be described in terms of classical physics. So, for example, the water balance of a reservoir is described. However, the biological reproduction differs in the fact that the elements of the reproducing system are created by the system itself, and only simple components for the construction of these elements come outside.

As long as the reproduction is an external function of the system, its evolution is either impossible or ineffective. However, if organisms and their relations are put in the basis of the reproduction, then the modelling in terms of classical physics, for example, of thermodynamics, become ineffective. This is primarily due to incomplete isolation of organisms, which does not allow one to equate them, for example, to gas molecules. Another reason lies in the fact that, for many species, an organism is not the basic unit of evolution.

Some researchers, especially those who tend to see the evolution as training only [28], disregard the role of combinatorics, or even omit the phenomenon of reproduction, facilitating the problem of phenomenological comparison of an ensemble of molecules and a population of organisms. We believe that the organism cannot be regarded as an equivalent to a gas molecule for a number of reasons, among which we have already called ontogeny, and now let us note the supraorganismal structure, the population.

The biologists have long agreed that the elementary unit of evolution is a population [29]. The phenomenon of the population structure of living systems deserves to be listed in the first principles, because the population is not a physical ensemble of stochastically mobile unified units. A biological population is a collection of organisms of the same species (shape), but of different sexes and age united by a common gene pool [29]. For this reason, a biological population cannot be described as an ideal gas, it contains at least two (on the basis of sex) classes of organisms, where organisms of different ages are found in different states (phases!) and, in order to obtain a common gene pool, a population must have a long history. The historical trajectory of a population consists of trajectories of ontogenesis, which are in a variety of biological and social relations. The most important biological relation in this case is sexual process.

The sexual process between members of a population makes the population a genetically closed system, and the sexual process with members of other populations opens it. The closing of a population reduces the potential of its variability, up to degeneration, and, when opened, the heredity is violated, up to the death of the offspring. Both facts make its quantitative contribution to the reproduction.

2.2.4. Sexual Process. The sexual process is often replaced by the term sexual reproduction, which introduces confusion and leads away from the understanding of evolutionary mechanisms. We believe that, in the course of reproduction, the growth of the number of organisms is achieved, while, in the sexual process, the growth of diversity is realized. The growth of diversity is important for searches of survival niches, and two levels of searches can be distinguished in it. At the first level, the fact that the activity of genes depends on their position in the chromosome is used. Here, the increase in diversity is achieved by the fact that genes and linkage groups of genes change the position on the chromosome during the crossing over during the formation of gametes, and then, when a zygote is formed, new combinations of gene positions in DNA are created. At the second level, the dynamics of gene states enters into the recombination of features of the future organism, which is discussed below. These two mechanisms, together with mechanism of mutations, underlie the variability that accelerates the evolution. If mutations can be attributed to the function of the environment, then the combinatorial processes at the current stage of formation are the internal functions of living systems. Such internal functions are absent for nonliving systems.

For the mathematical representation of birth and the sexual process, one can use the apparatus described by Fock in 1932 [4]. In this report, Fock used the second quantization method to pass from a linear operator to a nonlinear one. It is the transition to nonlinearity that opens the way to diversity of representations of living systems. The biological filling of the transition was started by Mendel long before its mathematical formulation.

3. MENDELIAN HYBRIDS

Mendel discovered the laws of inheritance of some characteristics of organisms when crossing pure lines of peas [30]. Now this observation is immediately associated with the phenomenology of pure states in physics. Pure states do not occur in nature, although they are experimentally possible for both classical and quantum systems. However, in biology, pure lines are also not at all an achievement of evolution. In biology, such experimental systems are resulting from many recurrent crosses (self fertilization). Getting a pure line in biology should be understood as a path to artificial closure of a system according to the selected feature.

The closeness is a necessary condition for pure lines in physics, but not impossible for clopen systems. Mendel reduced the state of a living system to the state a pure line to understand the mechanism of interaction of "purified" features. The effectiveness of recurrent crosses in obtaining of pure lines indicates that a population with a sexual process is represented by a factorized set in which two sets of features (genes in two types of gametes) are multipliers and the zygote is their product, the actual object. This is an analogy with a pure state in physics, and the probabilistic nature of Mendel's splitting law encourages to use the formalism of quantum mechanics to describe the results of crossing. However, here it is necessary to recall that the concept of a clean line in biology and a pure state in physics do not quite coincide. While, in physics, a pure state is associated with *one* (a single) vector, we see that, in biology the purity of a line is determined by the homozygosity of the object, i.e., the presence of *two* alleles in the same state. This circumstance, which complicates the Mendelian dynamics, is considered in context of the origin of life even rarer, although, if the cell is regarded as an interferometer for allelic states, then it is clear that this part of the biological information obeys the laws of quantum mechanics (optics). The recognition of this fact has far-reaching implications for the choice of models.

4. ALL THIS IS FROM A QUBIT

The combinatorial variability induced by the system itself is closely related in evolution with the need to "overlap" the changes in the environment and survive, arriving in favorable conditions. Although every organism has some adaptive variability and adapts during ontogenesis, the transfer of these changes to generations is problematic, which reduces their evolutionary contribution. The sexual process generates the combinatorial variability by recombining genes at the level of gametes than significantly expands the space of features that contribute to the descendants of successful pairs to avoid the extinction due the negative selection. But even this is not enough for the evolution of living systems, seeking to increase diversity. To achieve greater diversity in life, a polarization is used, the representation of genes in a state "dominance/recessivity," where the diversity of phenotypes achieved by the "simple" gene recombination is increased by distinguishing the state of the gene. The possibilities of polarization are further expanded by the mechanism of co-dominance, a well-known example of which is the inheritance of the blood group in a human being.

The genetic algorithm of life, as opposed to the Holland genetic algorithm, works at the levels of states and thus approaches the model of quantum computer.

The idea of a quantum computer is perhaps one of the few ones in which the unconscious imitation of living systems began to be carried out before the molecular mechanism of the phenomenon became clear to biologists. Although the idea of dominance was formulated by Mendel by 1866, much in the realization of dominance remains unclear till now. A typical description of dominance is given in the project "Human Genome..." on July 25, 2022 as follows: "Biochemically, what is going on in this case is that the genetic variation, for a variety of reasons, can either induce a function in a cell, which is either very advantageous or very detrimental, which the other version of the gene can't cover up or compensate for" (https://www.genome.gov/genetics-glossary/Dominant). Today we know about "for a variety of reasons" almost as little as in the years when Wiesner and Feynman first proposed the idea of constructing a quantum computer. But we know now that the space of quantum states of many-particle systems grows as an exponent of the number of real particles that make them up, and that the difficulties of simulation of their behavior on classical computers begin already for systems with tens elements. If we regard the gene as a particle of information and remember that the number of only the genes programming a protein in humans is approximately equal to 20,000 (CHESS-base), then it is easy to imagine the difficulties with which the evolution has encountered along the way of its optimization.

Wheeler in 1989, writing the famous [31]: ⟨It from bit⟩, remained in representations of bits, but he did not specify the state of the photon, and this left the ability for the transition to representations with qubits. If one sets a correspondence between the states of a quantum system and information concepts, then quantum systems can be regarded as information devices. Here two-level quantum systems turn out to be distinguished (an example is photon), which became the physical realization of the idea of a qubit. In the general case, the state of a photon with a certain momentum is a superposition of its two polarization eigenstates, i.e., is mixed. The state of the qubit is often represented as arrows on the Bloch sphere [32]. If we imagine the Bloch sphere as a model of the *fitness* space, then the variety of positions of the qubit arrow leads to a more complete and uniform coverage of the sphere, which corresponds to an increase in the chances of a qubit organism to enter the zone where it is the most fit.

In life, every organism becomes a version of a test of how well the resulting combination corresponds to the environmental conditions in a given place and in a given moment. Thus, life itself, the set of its ontogenies, can be regarded as a distributed calculator, first of the fitness, and then of the anticipation, the predictive property of living systems, which, according to Rosen [17], begins, from the moment of his invention, to determine the direction of evolution of living systems towards the creation of diversity. All this together can be perceived as a solution to an optimization problem, where it is important to use such areas of optimization as nonlinear, discrete, and dynamical. And the diversity of the phenomena of representation of the living, described in the paper, gives reason to believe that inventive Life in the course of co-evolution attempted, in each of them, achieving that the variability of the environment was overlapped with the variability of organisms. Unfortunately, in science, it is still widespread the idea "that coevolution is a rare and quirky sideshow to the main evolutionary acts shaping the diversity of life on a day-to-day basis" [33].

Till now (on Earth), the existing variability of living systems was enough to survive catastrophic fluctuations in environmental parameters, but the amplitude of natural change shows an upward trend, while resources for practical maintenance of a sufficient number and variety of people becomes less and less [34].

5. CONCLUSION

We started this paper by quoting the title of Wigner's paper. There is also such a place: " this uncanny usefulness of mathematical concepts that raises the question of the uniqueness of our physical theories" [1]. We believe that now there are grounds to talk about the effectiveness of mathematics in biology as well (cf. also [35]). Although we are not sure what exactly I. Gelfand was talking about inefficiency of mathematics in biology, we believe that classical mathematics gave in where the described object or phenomenon could be regarded as something incompletely discrete, but not quite analogous either. If this is the case, then further advances in mathematics in the study of life will be associated with the formation of ideas about the clopen properties of the components of a living reality: information, time, and space.

We, as the authors of this paper, clearly understand that, presenting the origin of life as an event of a series of information mappings (mapping of layers, "dominance/recessivity," including "bit/qubit"), we transfer our searches in an area which is not only poorly studied, but also is fundamentally difficult to study, to an area where there are no flows of matter so *familiar* to us. However, the first principles of living systems listed here convince us that, to look for the origin of life in the area of transition from chemistry to prebiology, is to look for where it is light.

If, according to our assumptions and in agreement with Wheeler, "*It*," timed to coincide with " to the very bottom," is an information-wave background both for the living and for the nonliving, only mathematics that describes this area will create a theory the origin of "everything," including life. Applied mathematics, in the form of informatics, masters new computing technologies, borrowing mainly methods of working with information in life itself: genetic and quantum algorithms, neural networks, and annealing are important milestones on the way to this borrowing. These successes are not accidental, they are provided by equifinality of studies of nature, where different paths can lead to the same results. For example, Fock introduced filling numbers for multiparticle systems [4], which are actually the foundations of computer science. A close approach, in our opinion, was used by Maslov [5, 36] to calculate the distribution of nonequivalent mappings, where it was shown that "an experiment, which for the same data could be different every time, must coincide in the mean."

These observations, together with the examples given in the paper, convince us that the mutual correspondence between the phenomena of biology and axioms of mathematics is located " to the very bottom" of becoming.

REFERENCES

[1] E. P. Wigner "The Unreasonable Effectiveness of Mathematics in the Natural Sciences," *Comm. Pure Appl. Math.*, **131** (1960), 1–14.

[2] V. I. Arnold "On Teaching Mathematics," *Russ. Math. Surveys*, **53**:1 (1998), 229–236.

[3] P. C. W. Davies "Does Quantum Mechanics Play a Non-trivial Role in Life?," *BioSystems*, **78** (2004), 69–79.

[4] V. Fock "Konfigurationsraum und zweite Quantelung," *Z. Physik*, **75** (1932), 622–647.

[5] V. P. Maslov "On a General Theorem of Set Theory Leading to the Gibbs, Bose–Einstein, and Pareto Distributions as well as to the Zipf–Mandelbrot Law for the Stock Market," *Math. Notes*, **78**:6 (2005), 807–813.

[6] J. von Neumann, *Theory of Self-Reproducing Automata*, University of Illinois Press, Urbana and London, 1966.

[7] J. Holland, *Adaptation in Natural and Artificial Systems*, MIT Press, Cambridge, MA, 1992.

[8] W. S. McCulloch and W. Pitts "A Logical Calculus of the Ideas Immanent in Nervous Activity," *Bull. Math. Biophys.*, **5** (1943), 115–133.

[9] O. Caramello "The Unification of Mathematics via Topos Theory," 2010.

[10] V. Voevodsky "An Experimental Library of Formalized Mathematics Based on the Univalent Foundations," *Math. Structures Comput. Sci.*, **25**:5 (2015), 1278–1294.

[11] E. T. Jaynes, *Probability Theory: The Logic of Science*, Cambridge University Press, 2003.

[12] M. Gromov, *Interview*, Rigas Laiks 1, 2014.

[13] D. W. Thompson, *On Growth and Form*, Cambridge University Press, Cambridge, 1992.

[14] D. J. Taylor, N. P. O. Green, G. W. Staut, and R. Soper, *Biological Science 1 & 2*, Cambridge University Press, Cambridge, 2004.

[15] L. von Bertalanffy "The Theory of Open Systems in Physics and Biology," *Science*, **111**:2872 (1950), 23–29.

[16] R. P. Feynman, *QED: The Strange Theory of Light and Matter*, Penguin Books, 1990.

[17] R. Rosen, *Life Itself: A Comprehensive Inquiry into the Nature, Origin, and Fabrication of Life*, Columbia University Press, New York, 1991.

[18] L. Brillouin, *Science and Information Theory*, Dover Publications, 2013.

[19] S. A. Kauffman "The Adjacent Possible," *Life: The Leading Edge of Evolutionary Biology, Genetics, Anthropology, and Environmental Science, Harper Perennial* 2016, 358–360.

[20] G. Nicolis and I. Prigogine, *Self-Organization in Nonequilibrium Systems*, Wiley-Interscience, NewYork, 1977.

[21] I. Prigogine and I. Stengers, *Order Out of Chaos: Man's New Dialogue with Nature*, Heinemann, London, 1984.

[22] S. J. Gould, *Ontogeny and Phylogeny (The Belknap Press of Harvard University Press)*, Cambridge, 1977.

[23] J. Lovelock, *Novacene: The Coming Age of Hyperintelligence*, The MIT Press, 2019.

[24] P. P. Amaral, M.E. Dinger, T. R. Mercer, and J. S. Mattick, *The Eukaryotic Genome as an RNA Machine*, **319**, Science, 2008.

[25] C. Shannon "A Mathematical Theory of Communication," *The Bell System Technical Journal*, **27**:3 (1948), 379–423, 623–656.

[26] N. Chomsky *Walter de Gruyter* 1972.

[27] D. Cram "Preorganization – From Solvents to Spherands," *Angewandte Chemie-international Edition*, **25**:12 (1986), 1039–1057.

[28] V. Vanchurin, Yu. I. Wolf, E. V. Koonin, and M. I. Katsnelson, *Thermodynamics of Evolution and the Origin of Life*, PNAS 119(6) e2120042119, 2022.

[29] J. Huxley, *Evolution: The Modern Synthesis*, Harper and Brothers, 1943.

[30] G. Mendel "Versuche Uber Plflanzenhybriden," *Verhandlungen des naturforschenden Vereines in Brunn*, **4** (1866), 3–47.

[31] J. A. Wheeler "Information, Physics, Quantum: The Search for Links," *in Proceedings III International Symposium on Foundations of Quantum Mechanics* 1989, 354–358.

[32] M. A. Nielsen and I. L. Chuang, *Quantum Computation and Quantum Information*, Cambridge University Press, 2011.

[33] S. L. Nuismer, B. Week, and L. J. Harmon "Uncovering Cryptic Coevolution," *The American Naturalist*, **199**:6 (2022), 869–880.

[34] W. J. Ripple, C. Wolf, T. M. Newsome, M. Galetti, M. Alamgir, E. Crist, M.I. Mahmoud, W.F. Laurance, 15,364 scientist signatories from 184 countries "World Scientists' Warning to Humanity: A Second Notice," *BioScience*, **67**:12 (2017), 1026–1028.

[35] Yu. N. Zhuravlev, M. A. Guzev, and A. I. Gudimenko "Protein Synthesis as an Object of Physical and Mathematical Research and Modeling," *Siberian Electronic Mathematical Reports*, **16** (2019), 340–368.

[36] V. P. Maslov "Violation of the Determinacy Principle of Nonstationary Equations of Two- and Three-dimensional Gas Dynamics for Sufficiently Large Reynolds Numbers," *Theor. Math. Phys.*, **69** (1986), 1202–1212.