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Quantum-like model of partially directed evolution

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A B S T R A C T

The background of this study is that models of the evolution of living systems are based mainly on the evolution of replicators and cannot explain many of the properties of biological systems such as the existence of the sexes, molecular exaptation and others. The purpose of this study is to build a complete model of the evolution of organisms based on a combination of quantum-like models and models based on partial directivity of evolution. We also used optimal control theory for evolution modeling. We found that partial directivity of evolution is necessary for the explanation of the properties of an evolving system such as the stability of evolutionary strategies, aging and death, the presence of the sexes. The proposed model represents a systems approach to the evolution of species and will facilitate the understanding of the evolution and biology as a whole.

Contents

1. Introduction

The background of this study is that current theories of evolution are based on a large number of facts related to the effects of genes, epigenetic effects, molecular-genetic control systems and

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developmental biology. However, the theoretical basis of these mechanisms is insufficient. There is a lack of modeling from first principles using well-defined terms.

Models of the evolution of living systems are based mainly on the evolution of replicators. Although replicators provide a useful paradigm for the early stages of evolution, this concept must be substantially modified to simulate the evolution of organisms. Replicator models provide only a qualitative representation of evolution and cannot explain many of the properties of biological systems such as the existence of the sexes, molecular exaptation, aging and others. On the other hand, attempts to modernize the theory of evolution are largely unformalized, and many important concepts are often poorly defined. Thus, in the modern theory of evolution, challenges remain. Such problems include, for example, issues such as the existence of the sexes and horizontal gene transfer. In what cases and for what systems are these strategies effective? A complex process of gene changes is also needed in the most general consideration. One promising area for such a simulation is the theory of automata. Von Neumann was the first to propose a model of automata that could reproduce themselves (von Neumann and Burks, 1966). Later, the theory of adaptive (learning) automata arose, one of whose founders was Tsetlin (1963). This theory was further developed by Narendra and Thathachar (1989).

To solve the problem of enumeration of variants, a model of partially directed evolution was proposed by Melkikh (2014a, 2014b, 2015). One of the main provisions of the model is that quantum mechanics plays an important role in the evolution of species.

On the other hand, there is a relatively recent and successfully developing trend (see, for example, Khrennikov, 2010) in modeling the behavior of living systems as quantum-like behavior. At the heart of this trend is the assumption that the decision-making of humans described by biological laws is in many respects similar to the models proposed by quantum mechanics. In particular, we are talking about the fact that in this case, amplitudes of probabilities added. On the basis of this approach, solutions to a number of decision-making paradoxes were proposed. There exist quantum models of exaptation (Gabora et al., 2013) and epigenetic inheritance (Asano et al., 2013). However, such effects are only part of the multi-faceted picture of evolution. A broader perspective would be provided by a common approach to evolution on the basis of quantum-like dynamics, which would explain evolution on the basis of the united positions of a large number of evolutionary phenomena.

The purpose of this article is to build a complete model of the evolution of organisms based on a combination of quantum-like models and models based on partial directivity of evolution. Using this model, it should be possible to explain a wide range of evolutionary phenomena. The proposed model represents a systems approach to the evolution of species and will facilitate the understanding of the mechanisms of evolution.

2. Quantum models of evolution

Quantum models of evolution can be divided into two classes, those based on quantum dynamics and those based on quantum-like dynamics. In the first case, an evolving system is considered a quantum on the basis of the quantum properties of its individual particles. Significant problem for this case is the decoherence. In the second case, the authors do not consider quantum properties of particles but consider that quantum dynamics provides a convenient tool for the mathematical modeling of some properties of evolving systems.

Let us discuss briefly models in the evolution of species (for more details see, Melkikh, 2014a; Melkikh and Khrennikov, 2015).

The evolutionary game may feature, in addition to classical dynamics, also quantum dynamics. This issue has been the subject of many articles (see, for example, Hidalgo, 2006).

The peculiarity of quantum replicator games is that replicators can be in mixed and in pure states. The latter means that the replicator may be in several states simultaneously. System dynamics for pure states can be described by the von Neumann-Liouville equation:

$$i\hbar\frac{d\rho}{dt} = [H(t), \rho(t)],$$

where $H(t)$ − is the Hamiltonian of the system and $\rho(t)$ − is the density matrix.

The prisoner's dilemma and cooperation in quantum games are considered in (Li et al., 2013a; 2013b). Aerts et.al. (2014) examined the quantum model of evolution in a population of lizards. The non-triviality of this situation lies in the fact that three forms of one species of lizard (*Uta stansburiana*) compete with each other so that their strategy cycles dominate each other (the yellow form dominates the red, red is dominant over blue, and yellow dominates blue). The authors proposed rules for constructing the Hilbert space for the probabilities with respect to the considered game model.

However, it remains unclear whether the wave function in this case is simply a convenient way of describing the actual quantum behavior of the gene(s), the genome or the organism.

On the other hand, it is possible that quantum mechanics is really important for genes behavior. Melkikh and Khrennikov (2015) put forward arguments in favor of the fact that quantum mechanics plays an important role in the process of mutation and in the process of DNA folding. What, for example, determines the probability of crossing over of a particular gene of one of the parents? Is such a process due to thermal fluctuation, or does its probability have a quantum nature? These questions can be answered by conducting special experiments, some of which were discussed in Melkikh and Khrennikov (2015).

Gabora et.al. (2013) note that classical physics is insufficient to simulate the exaptation process. The authors suggest a quantum model of exaptation based on the assumption that the implementation of the various features is non-additive and obeys the laws of quantum mechanics.

As a test of their hypothesis, the authors proposed to analyze the additivity of individual traits of organisms occurring in the course of evolution. According to the authors, such an experiment would be an analogue of the classic double-slit experiment in which such non-additivity also takes place.

Bordonado and Ogryzko (2013) suggest that adaptive mutation is the result of quantum interference (i.e., finding the cells in the two genetic conditions simultaneously). At the same time, of two states, the one that is most adequate to meet the survival of cells in a given environment is selected. The concept of basis-dependent selection for biological objects, which is based on an analogy with quantum phenomena, was introduced.

A quantum-like model of epigenetic evolution was constructed by Asano et.al. (2013). The authors note that there are several types of epigenetic inheritance, the details of which are not fully understood. It is necessary to create a unified model of this process.

The proposed model is based on the theory of open quantum systems. On the other hand, the authors use the results of quantum-like (QL) dynamics proposed previously for a broad class of systems (see, e.g., Khrennikov, 2010). One of the important provisions of this approach is violation of the classical laws of probability and information.

At the initial time, a pure quantum state describes the superposition of the epigenome. As a result of decoherence with the