A Natural Brain for Intelligent Design

A new scientific concept for biological evolution

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Foreword

The discussion about Intelligent Design -- fed by political controversy -- is heating up, as evidenced by recent editorials in USA Today ("Faith, science complement each other," August 16, 2005, and "New school year, new battle over evolution," August 26, 2005). Yet a solution exists that can pacify the frenzy.

The main question of the discussion is the following: Is Intelligent Design a science or religion? Unfortunately, today it is both.

The science part: It is a scientific fact that normal evolution through haphazard mutation and selection could not have created certain complex biological structures in the available timeframe. A possible explanation for this paradox is that the evolution of a species is not random but is subjected to guidance (intelligent design) that streamlines the evolutionary process. This explanation appears scientific -- with calculations, formulated discrepancies in the existing theory, and a possible direction that resolves these problems.

But now comes the difficult part: Who is this intelligent guide capable of influencing evolution? So far, the only candidate for this role is an almighty God, and this is not a scientific solution. (The existence of God is a matter of faith rather than scientific proof.) At the same time we have no reason to believe that Little Green Extraterrestrials are responsible. If we could only find another plausible candidate -- one with a physical rather than imaginary nature -- we could keep things in the realm of science and take religion out of the equation.

The authors are specialists in technological evolution. In the mid-1980s we conducted in-depth studies of biological evolution theory for the purpose of identifying useful analogies between natural and technological evolution. We were surprised by the numerous discrepancies in the theory of natural evolution (the "intelligent design" problem is just one of more than a dozen). In the process of seeking a solution to explain the discrepancies, we developed a theory that explains intelligent design without God's involvement. In 1986 we reported and discussed our findings with evolution specialists; they were outraged, yet could offer no scientific objections to the theory. For the next 20 years as we worked on other matters we kept our eye on the subject, and it still looks promising (additional data accumulated over the last two decades supports our view).

This paper is a result of applying the TRIZ approach to the process of solving scientific problems and generating new scientific concepts.[2]

The processes for solving scientific problems and generating new scientific concepts are based on the same approach -- *problem inversion*. The essence of this approach is simple: instead of asking, "How can a certain phenomenon be explained?" we ask "How can this phenomenon be

created under the given conditions?" The problem then becomes a typical inventive problem and can be attacked using existing TRIZ tools such as the Innovation Principles, ARIZ, System of Operators, etc.[3] Based on this approach, a process was developed for building new scientific concepts (see the Appendix).

To test the usefulness of the problem inversion approach for generating new scientific concepts, the authors applied it to several areas, including organization theory and biological evolution. This paper describes the process and results of our efforts to invent a new concept of biological evolution. The process/results were first presented in 1985 at the TRIZ Congress in Petrozavodsk, Russia.[4] The hypothesis was revisited in 1988 at a TRIZ seminar conducted by Boris Zlotin and Dr. Gafur Zainiev at the Institute of Cytology and Genetics at the Siberian division (Novosibirsk) of the Soviet Union Academy of Science.

The report presented at the TRIZ Congress and later in Novosibirsk generated much controversy. Our TRIZ colleagues were concerned that attempts to break into such highly specialized areas -- especially with a hypothesis that seemed more like fantasy than reality -- would compromise TRIZ in the eyes of professionals. For their part, professional evolutionists were (to say the least) extremely skeptical as well. But over the next 20 years, no facts were brought to light that could invalidate the hypothesis.

Introduction

It is no surprise that TRIZ specialists have long been interested in biological evolution -- biology was one of the first sciences in which evolutionary laws were discovered. An analysis of the work of famous biologists-evolutionists (Shmalgayzen, Lubischtev, Yablokov, Timofeev-Resovsky, Berg and others) has shown that it is fitting to compare the patterns revealed for technological evolution with those of biological evolution. There are many similarities, but also significant differences. For example, some patterns well known in biology have not yet surfaced in technology, and vice versa.

Our original intention was to learn the patterns of biological evolution and transfer them to TRIZ. Because we were not professional biologists we had to educate ourselves, starting with high school biology textbooks, continuing with college courses, and eventually studying monographs on various subjects (investing more than 1500 hours). Gradually this in-depth study began to reveal certain difficulties and even dilemmas (contradictions) in contemporary Darwinism, also called the Synthetic Theory of Evolution (STE). Since we were involved in developing TRIZ we decided to apply TRIZ elements and tools to biological dilemmas. Since then our efforts to develop a methodology for generating new scientific concepts and to develop new scientific concepts related to biological evolution have continued in parallel.

Our work resulted in the hypothesis of a nature-given brain for intelligent design that we believe, if proven, will complement STE. This hypothesis was first presented at the Third TRIZ Congress in Petrozavodsk in 1985. We continued working on it and in 1988 and 1989 presented and discussed it with professional biologists during TRIZ seminars at the Institute of Cytology and Genetics at the Siberian division of the Soviet Union Academy of Science. We also briefly described the hypothesis in the form of a science fiction idea in our children's book *A Month Under the Stars of Fantasy.*[5]

Initial model

The basic model of STE is well known: haphazard changes to live organisms due to genetic mutations, and the survival of the most adaptable species in the process of natural selection. This model adequately explains the underlying mechanisms of many biological processes, but demonstrates a number of crucial enigmas related to specific facts and phenomena.

Enigma 1. *Cephalization (from the Greek word* kephal*, meaning "head") refers to the evolutionary trend of mental and psychological capabilities evidenced by the ratio of brain mass to body mass. It seems logical that with the growth of cephalization the "pressure" of natural selection should become less, because a more psychologically developed organism can compensate for negative impacts from the environment through behavioral changes and adaptation. For example, unusually cold weather can kill heat-loving fish, while foxes and monkeys learn to avoid cold by hiding in ground holes, creating shelters from dead leaves, and so on. The development of mental capabilities should help animals survive because it provides for better caring of the brood, gathering in flocks, the sharing responsibilities, etc., lowering the pressure of natural selection. This means that the growth in brain mass should slow the organism's evolution -- however, paleontological research reveals the opposite: evolution speeds up with cephalization. There is no satisfactory explanation for this phenomenon.*

Enigma 2. *Estimations of the probability of the appearance of certain biological features proves that relatively few generations and a limited number of species (i.e., a relatively small number of variants to explore) make complex biological organisms unlikely to appear under the conditions of haphazard mutation and selection. There have been several moderately satisfactory attempts to explain this phenomena, but no general agreement exists.*

Enigma 3. *The selection theory does not adequately explain the evolution of features (organs) that are not functional in infancy yet continue to evolve (e.g., the electric organs of the electric ray). Nor does it explain the development of advanced features before the need has arisen (seams in the skulls of mammals, for example), or of features that are useful for the entire species but harmful for an individual specimen (such as the rattle of a rattlesnake).*

Enigma 4. *Biological evolution asserts that its main purpose is to ensure the survival of the species rather than the individual. If this is so, it seems preposterously excessive to have an organ as powerful as the human brain or nervous system for the exclusive purpose of individual survival.*

Enigma 5. *To explain the reasons for the development of useful mutations, several hypotheses for the natural inventiveness of live organisms have been offered. The first referred to "embryo inventiveness"; as biology evolved, inventiveness was attributed to cells, genes, molecules, and so on. In effect, the responsibility for biological invention has been moving deeper and deeper to the micro-level. But where does it end?*

Analyzing the theory of biological evolution in light of TRIZ has led to an interesting conclusion: similar to the way TRIZ has evolved, the "battle line" in bio-evolution lies in the evaluation of the role of trial-and-error -- that is, the haphazard exploration of variants.

As mentioned earlier, the Synthetic Theory of Evolution (STE) holds that bio-evolution is a result of haphazard mutations (the exploration of variants). However, a number of noted biologists-evolutionists, among them L. S. Berg and A. A. Lubischtev, disagree with this theory. In its place they offer models of evolution based on the assumption that patterns of biological evolution exist (Berg's nomogenesis theory[6]) or that one or more end-seeking factors are responsible for guiding evolution in a desirable direction (finalist theories of evolution[7]). In the finalist theories the candidates for the role of this factor are wide-ranging: from God to "programmed evolution." Yet these models are not free of problems, either. If purposeful evolution exits, why is it so slow? And why does it allow so many failures such as dead ends, the elimination of an entire species, etc.? The war between STE apologists and nomogenesists has been going on for some time, exposing considerable differences between the theories.

In addition to the difficulties mentioned above are less crucial problems in biological theory. Explanations have been offered that eliminate certain contradictions, but many of these are ad hoc hypotheses capable of justifying whatever is needed. The sum total of these explanations (and there are many in STE theory) makes the subject too complex and rather clumsy, lacking the elegance of a true theory. Clearly bio-evolution theory is in need of serious reexamination and restructuring that will allow all of the related factors to be explained from a single methodological platform.

Inverting the problem

Let us imagine that we have been tasked with designing a mechanism capable of managing evolution -- that is, a means of enhancing a biological organism toward its most ideal state in the most direct and expeditious way. We are seeking, it would seem, to build an "electronic brain for directing evolution," or an expert system for intelligent design. This brain must be able to solve problems such as: Would the ideality of a deer increase if its neck were longer? On the one hand, the number of useful functions would increase because the deer would be able to reach higher branches to obtain food. On the other hand, the harmful factors would increase as well: a longer neck calls for a stronger skeleton to carry the head; providing blood to the end of a longer neck requires a more powerful heart, which will eventually lead to higher body mass and thus increase the food required for survival. The brain for intelligent design must weigh the advantages and disadvantages and then decide whether a "suggested" mutation is beneficial. If there is no benefit, the variant must be rejected without being field-tested, and new variants explored. If there is a possible benefit, the brain must command the genetic mechanism to start implementing the "innovation."

Let us summarize the requirements for the mechanism we are seeking. Evidently it must be able to:

- Consider available models of the given organism, then select and test (mentally) various changes to the organism in a particular environment.
- Amass information about variants that have been attempted in the past in order to avoid the same failures.
- Establish a set of rules that define preferable directions, exclude seemingly wrong paths, and limit the number of trials; in other words, possess knowledge of applicable evolutionary patterns.
- Influence genetic mechanisms that will test the results of mental selection in a real environment.

Of course, a sufficiently powerful computer could satisfy these requirements. But a live brain can do so as well.

Interestingly, most finalistic theories were seeking such a brain as an external entity to the organism, inevitably getting mired in mystique. TRIZ, on the other hand, recommends a thorough search for available resources. And in this case, the only available resource that fulfills the requirements is the brain of the evolving organism.

Given the above, the following hypothesis can be formulated: ***The evolution of a live organism can be guided by its own brain and nervous system***, as these possess practically all the required capabilities. Even the brains of relatively simple organisms can formulate and resolve problems based on an adequate model of the environment and of the organism itself,[8] so long as they possess certain computation abilities that will allow them to "calculate" a simple evolutionary jump, not to mention much more complex reactive and adaptive behavior. The brain, however, is

capable of accumulating both operational and genetic information (i.e., knowledge about the complex instincts of animals).

In the past there was a lack of information as to whether it was possible to exert a "natural" influence on genes. But recent research conducted by V. A. Geodakyan[9] in gender theory shows that it might indeed be possible. A simple mechanism for creating this influence might be the natural selection of the best (from an evolutionary point of view) mate. A less obvious mechanism was suggested by biologist and TRIZ specialist Dr. G. A. Zainiev,[10] who believes that rather than influencing the structure of DNA molecules, such a mechanism can control DNA *activity* -- that is, activate a switch that changes certain links (genes) within the DNA structure so that they become dominant.

This hypothesis -- that an organism's evolution can be guided by its brain and nervous system -- resolves the complex issues and contradictions discussed earlier. It explains why fewer generations are required compared to the calculated number: many of the "trials" can be made "mentally." Moreover, the more advanced the brain, the more effectively it can solve evolutionary tasks, and the faster the evolution (in accordance with the actual process) can take place. The hypothesis also explains certain failures, as the brain for intelligent design cannot possess all the information necessary to predict results many generations in the future. In fact its capabilities are rather limited, allowing it to identify relatively short-term directions that will benefit the lives of its successors only slightly better (or at least not worse) than it will benefit its own life.

The hypothesis of a brain for intelligent design leads to the assumption that an organism's "inventiveness" should, instead of being transferred from molecules to elementary particles, be replaced with the inventiveness of the previous system -- that is, the parental organisms. It is also possible that the brain and nervous system have evolved as tools to promote survival and evolution in the first place. The hypothesis can also easily explain the appearance of advanced features, collective adaptations, and organs that are not useful until fully developed.

Verifying the hypothesis

The following facts support the hypothesis of a brain for intelligent design:

Alfred Wallace proposed a theory of biological evolution as a result of natural selection almost simultaneously with Darwin. Later, however, he abandoned the idea because it could not explain the emergence and rapid development of the human brain. Nor could it resolve the fact that the complexity of a brain powerful enough to survive in our multi-faceted lives conflicts with the relatively simple conditions that exist when the brain is formed. From the point of view of our hypothesis this mismatch can be explained as follows: human intellect forms as a result of a rapid (compared to evolutionary processes) "switch" from focusing solely on evolution to utilizing some portion of its computational power for everyday life. We can also explain the phenomenon of excessive brain power with which the brain, formed in ancient times on relatively simple tasks, can successfully handle the problems of today. It also explains why evolution accelerated so strongly with the appearance of humans then practically stopped after Cro-Magnon: it is possible that the brain switched entirely from evolution to everyday tasks.

In addition, this hypothesis explains why the range of brain capability is significantly wider than that of other organs -- different people or organisms have different brain volumes to be switched. Such abnormal brain phenomenon as super-memory, high-speed mental computation, etc. are rendered understandable. We might also assume that this switching can be controlled and/or trained so that a human can, from the biological point of view, become smarter.

The brain for intelligent design hypothesis is compatible and complementary to Geodakyan's genetic theory of gender. It is also fairly compatible with the Synthetic Theory of Evolution if one

assumes the coexistence of both mechanisms for mutation -- haphazard and purposeful. It is also possible that, as it evolves further, the human brain will re-assign some of its power back to evolutionary tasks.

What sort of objections can we expect against this hypothesis? For one, it appears that it cannot explain the evolution of plants, as they do not have brains. It is possible, however, that the role of a brain could be performed by certain nerve groups such as ganglia in insects. And we cannot exclude the possibility that specific cells exist to perform a necessary function (nowadays we hear about cell or molecular computers). In point of fact, the question of how plants evolve and whether or not they have some brain-like power capable of guiding their evolution could become the *experimentum crucis* on which the hypothesis is confirmed or rejected.

Real verification of a hypothesis of this kind usually requires a substantial amount of work that includes studying the entire complex of known facts, phenomena and mechanisms and examining how they comply with the hypothesis. In addition, experiments should be designed that will prove or disprove the conclusions. It is clear that this work can only be conducted by subject matter experts in the area. We can also expect that the hypothesis, in the process of verification, will undergo clarification, correction and enhancement.

Further developing the concept

The main point of the concept we are addressing here is that the brain of an organism is utilized as a functional resource. In other words, in addition to its accepted function of ensuring the organism's survival over its individual life cycle, the brain is capable of performing the additional (and no less important) function of guiding the organism's evolution. And if we extend this line of reasoning we can assume that the brain can perform other useful functions as well.

One of the problems with gene theory relates to the extremely high informational density of a genome (a combination of genes). The genome must carry the enormous amount of information necessary to build an organism, coordinate the growth of various organs, code numerous instincts, etc. It seems that some of these functions could be performed by the brain. For example, after its initial formation an embryo's brain could control the development of the embryo.

As the embryo develops the brain continues to develop as well. And the maternal organism can serve the purpose of "coordinator." The whole process might look like an industrial process: The genome (project specification) defines the basic parameters of the future organism, while the maternal organism's brain implements the design according to the manufacturing conditions. Another variant: the maternal brain activates the brain of the embryo. It is also possible to "download" certain information needed to form reflexes and instincts, similar to the transfer of information from one computer to another. This mechanism for transferring information might not support the full growth of the complex live organism *in vitro*, thus making a long gestation period an evolutionary benefit (the usual explanation is that a long pregnancy increases the ability of the fetus to survive). This explanation might fall short, however, as long gestations also create delivery problems and endanger the mother's life.

Expanding on the idea of utilizing the informational resources of the brain and nervous system, it is easy to see that if the above hypothesis is correct, Mother Nature must offer another informational mechanism to allow for the exchange of useful evolutionary information between adults. How to build such a mechanism? It could work on the basis of synergistic effects. Similar mechanisms exist: self-synchronization in glowworms, the so-called crowd effect, and so on. Another (and rather fantastic) way is telepathy. A third way might be the exchange of information during intercourse, which provides the tightest contact between the nervous systems of two specimens of different gender, while brain control is usually shut down (another analogy with information transfer from one computer to another).

The brain for intelligent design hypothesis is reminiscent of Lamarckism -- the theory developed by Lamarck[11] stating that the attributes gained over the lifetime of an individual organism are passed on to its offspring -- and especially the branch called psycho-Lamarckism. The basic concept of psycho-Lamarckism assumes that the organism might wish to change, and that these wishes influence the inheritance mechanism to bring about changes in its successors. Darwinists reject this notion because the mechanisms by which the psyche influences the inheritance process are unknown. Yet it is interesting that Darwinism and Lamarckism have been in competition for more than a century. Despite the fact that Darwinism is the recognized winner, Lamarckism reasserts itself from time to time, usually when relevant discoveries are made. The explanation for this relationship might well be that the theories are complementary[12] and should eventually be integrated into a single general theory, as happened earlier with the development of the Synthetic Theory of Evolution.

For example, perhaps new attribute information gained over an organism's lifetime does not affect the genes directly but instead is placed in an "operational memory" in the maternal organism and then transmitted to the fetus. If in several generations this new gain has proved useful and does not conflict with other requirements, it becomes "written" into the genes. This is analogous to a directive in military operations: when headwaters collect and intelligence information accumulates, validate it and select the information that has been confirmed multiple times.

If the brain for intelligent design hypothesis is true, and if its derivative regarding the reason for different intellectual levels in humans is correct, the following opportunity presents itself: reassign some of the brain's power from evolutionary tasks to individual life tasks, creating super-intellectuals who are capable of competing with computers.

Another derivative holds that if the reason that human evolution has, in every practical sense, stalled is related to the switch to daily tasks, once the switching mechanism is controlled humanity can assume the responsibility for its own evolution and evolve itself in a desirable direction.

Another curious derivative exists: if animals have, in principle, a powerful enough brain for intelligent design, switching might make it possible to create animals that possess intellect.

Evolutionists are of the opinion that the highest level of integration manifests itself in the evolution of evolutionary mechanisms -- a problem that is brand new in modern evolution theory.[13] It is interesting to consider the evolution of evolutionary tools in light of TRIZ principles, particularly the evolutionary pattern (or "law") called Decreasing Human Involvement.

In bio-evolution it is possible to track the first two stages in the decreasing application of trial-and-error. The evolution of the simplest organisms is carried out at the level of actual trials, without any memorizing of errors -- in other words, the wrong mutations were eliminated but could reappear in future generations. Syngenesis represents the transition to trials with memory. Mutations (both useful and harmful) were recorded in recessive genes, preventing the immediate elimination of unsuccessful mutants. This process led to a "bank" of genes capable of recording numerous mutations, including those that are useless at a particular evolutionary stage. When conditions change, however, certain mutations might become important for survival and quickly surface. Also, "genes memory" provides the means for integrating mutations into complexes, neutralizing harmful mutations, etc. The analogy to the utilization of higher levels of "creativity" (mental trials and the application of patterns) has not yet been confirmed in biological evolution. In this regard, the hypothesis of a brain for intelligent design allows these mechanisms to be realized, thereby filling the gap.

Let us summarize the above. It is obvious that a "brain for directing evolution" is capable of increasing the ideality of a live organism and advancing it along an evolutionary line. The hypothesis does not conflict with any important assumption and thus has the potential to be true. The precise mechanisms by which this activity takes place, however, are as yet unknown.

This hypothesis and its derivatives call for a more extensive application of information technology approaches to biology, the purpose being to learn about the informational processes of live organisms, including the influence of informational exchange on evolution. This conclusion is in complete accordance with the general direction in which technology and science (biology in particular) are evolving.

The brain for intelligent design hypothesis will no doubt incite a host of objections, especially from biologists. In anticipation of this we could offer more arguments to support the hypothesis, but at this point we do not believe this is necessary. It would be much more beneficial for the science of biology if this direction were to catch the attention of professional biologists that could analyze the matter and develop it further. In our opinion, it makes little difference whether such a brain exists or is only accepted as science fiction. For us its greater value is as an example of a method for inventing new scientific hypotheses -- i.e., a method that could help subject matter experts address scientific problems.

APPENDIX
Inventing New Scientific Concepts

STAGE 1. Analyze the existing system

Step 1a. Learn about the system's …
- Sub-systems
- Super-systems
- Structure
- Functioning
- Basic postulates and original facts
- Basic patterns and known mechanisms
- Evolutionary history and dynamics, basic trends and stages of evolution

Step 1b. Learn about other systems related to the targeted system (apply analogies based on similar phenomena, approaches, etc.)

Step 1c. Formulate and analyze a system model:
- Create a simple model
- Identify the basic sub-systems of the model
- Identify known limitations
- Try working with typical and universal models

Step 1d. Analyze the model's shortcomings in order to:
- Reveal facts inconsistent with general evolutionary patterns, including:
  -- Poorly-founded postulates
  -- Violations of accepted boundaries
  -- Internal contradictions
  -- Ad hoc hypotheses[14]
  -- Unsolved problems

- Reveal drawbacks associated with the current stage of the system's evolution (stagnation, for example)

- Formulate problems

STAGE 2. Synthesize a new concept

Step 2a. Solve formulated problems using scientific problem-solving techniques: the Problem Inversion approach, typical and universal explanatory mechanisms, etc.

Step 2b. Combine all results into a new, integrated model-concept that can complement or replace the original one. Structure the new concept and define its boundaries and limitations.

STAGE 3. Verify the new hypothesis

Step 3a. Check to see how the new concept fits the entire complex of facts and patterns existing in the applicable area.

Step 3b. Check to see how the new concept relates to other theories (i.e., that it complies with the principle of correspondence).[15]

Step 3c. Reveal new facts and patterns predicted by the new concept; solve problems related to verifying these facts (using TRIZ if necessary); conduct necessary verification experiments.

Step 3d. If one or more steps from 3a to 3c produce negative results, return to Stage 2 and formulate new problems related to the search for mechanisms that can explain the deviations.

STAGE 4. Develop the new concept further

Step 4a. Apply the patterns of evolution to the new concept, including:

- Formulate the opposite concept. Try to find the conditions under which this anti-concept might become valid. Find a way to combine the concept and anti-concept in accordance with the pattern of integration of alternative systems and the principle of complementarity.[16]

- Consider applying other patterns of evolution

Step 4b. Describe the new explanatory mechanisms that have been obtained. Consider whether then can be expanded to other areas.

NOTES

1. Edited by Victoria Roza.

2. Zlotin, Boris and Alla Zusman, comp. 1991. *Solving Scientific Problems*. Kishinev: STC Progress in association with Kartya Moldovenyaska (in Russian).

3. Zlotin, Boris et al. 2000. "TRIZ Beyond Technology: The Theory of the Non-Technical Application of TRIZ." Proceedings of TRIZCON 2000, the Altshuller Institute for TRIZ Studies.

4. Zlotin, Boris and Alla Zusman. 1985. "Utilizing TRIZ Tools to Solve Scientific Problems." Third Petrozavodsk TRIZ Congress. Reprinted by the Institute of Cytology and Genetics, Novosibirsk division of the Soviet Union Academy of Science.

5. Zlotin, Boris and Alla Zusman. 1988. *A Month Under the Stars of Fantasy*. Kishinev: Kartya Moldovenyaska Publishing House (in Russian).

6. Berg, L. S. 1977. *Works on Evolutionary Theory, 1922-1930*. Leningrad: Nauka Publishing House (in Russian).

7. Nazarov, V. I. 1984. *Finalism in Modern Evolution Theory*. Moscow: Nauka Publishing House (in Russian).

8. A lion is capable of making fairly precise "calculations" for a jump while hunting a gazelle; a ram can accurately jump from one rock to another in the mountains.

9. Geodakyan, V. A. 1989. "Gender Differentiation Theory in Problems of Humans." A collection of articles in *Humans and Science*. Moscow: Nayka Publishing house (in Russian).

10. Gafur Zainiev, a TRIZ scientist at Ideation International, holds a Ph.D. in microbiology.

11. Jean-Baptiste Pierre Antoine de Monet, Chevalier de Lamarck (1744-1829), a naturalist and Darwin's predecessor, is the author of the first integrated concept of natural evolution. (Translator's note).

12. The principle of complementary, suggested by physicist Niels Bohr, states that two contradictory theories can both be valid and complement one another. (Translator's note.)

13. Yablokov, A. V. and A. G. Yusupov. 1981. *Evolution Theory*. Second edition revised and expanded. Moscow: Vysshaya Shkola (in Russian).

14. An ad hoc hypothesis is a hypothesis introduced solely for the purpose of explaining a new fact, which is not connected to or correlated with other theories. (Translator's note.)

15. The principle of correspondence, introduced by physicist Niels Bohr, states that any new more general concept must include the old theory as a particular case. (Translator's note.)

16. The principle of complementarity, another principle introduced by Niels Bohr, states that two contradictory theories can both be valid and complement one another. (Translator's note.)

