

Evolution and Design

The Darwinian View of Evolution Is a Scientific Fact and Not an Ideology

PETER SCHUSTER

*Peter Schuster,
Editor in Chief of Complexity,
is at the Institut für Theoretische
Chemie der Universität Wien,
A-1090 Wien, Austria;
E-mail: pks@tbi.univie.ac.at*

On July 07, 2005 the *New York Times* published a letter submitted by the Roman Catholic Cardinal Christoph Schönborn. In this letter he raised the claim that nature provides evidence for intelligent design and criticizes evolutionary biologists for being unable to recognize the design. The letter reads: “Any system of thought that denies or seeks to explain away the overwhelming evidence for design in biology is ideology, not science.” and “Scientific theories that try to explain away the appearance of design as the result of ‘chance and necessity’ are not scientific at all, but ... an abdication of human intelligence.” Thereby, the Cardinal rejects the concept of evolution driven by random variation and selection, apostrophized as “chance and necessity” in the Neo-Darwinian spirit. The two quoted sentences are remarkable not only because the Cardinal aims at the recognition of intelligent design in nature but also because he accuses evolutionary biologists of adhering to an ideology. Almost all scientists who answered the letter reacted sharply because they felt that science has its own well-established rules for the dialog of the researcher with nature, and this dialog so far has not led to the necessity to assume a plan or a designer for understanding the evolution of the biosphere. The reaction of the nonscientific public, however, was ambiguous: Some answers were liberal and said: “Let the scientists do their job and define what science is about, and accordingly the Cardinal should care about belief and religion.” An appreciable fraction of letters to newspapers in response to the letter in the *New York Times*, however, welcomed the Cardinal’s position because they found that time has come to regulate scientific thought. Without digging into the deeper reasons of the somewhat burdened relation between science and laymen in the public, it seems in place to address some facts concerning the issues on which the most frequently invoked arguments for design are built. In the following six paragraphs an attempt is made to present these facts in the light of biology of today, which is more than 50 years after the formulation of the synthetic or Neo-Darwinian theory of evolution.

PROBABILITY ARGUMENTS IN FAVOR OF DESIGN ARE FUTILE

An argument often raised against evolution by variation and selection is the low probability to obtain one particular biomolecule or one organism (see, e.g., Eugene Wigner [1]). We present it here in a simplifying caricature: In order to find one particular genome of chain length one million nucleotides, the number of trials required to hit the target in a random search with probability one is $4^{1,000,000} \approx 10^{600,000}$. Although the mean path length would be smaller than a path visiting all sequences, the number is so incredibly

large that no appropriate statistics on path lengths could change the improbability argument. The calculation, however, suffers from a fundamental flaw because it implicitly assumes equal probabilities of realization for all paths through sequence space. This is certainly not true because natural selection inevitably starts to operate at the same instant at which reproduction began on the molecular level [2]. Let us make an estimate based on the other extreme: Every change in the sequence that reduces the distance to the target genome is accompanied by a selective advantage. Then, the combination of variation and selection at every step reduces drastically the number of steps required to reach target. In the least favorable case the number of steps along the “selection path” amounts to $3 \times 1,000,000$, because the distance to target can be reduced independently at each position in the sequence and the maximum number of changes is three at the individual position. One in three million, 3.333×10^{-7} , is not a small probability, because, for example, the lottery “6 out of 45” has a success probability of 1.71×10^{-10} . The number of steps required to reach a particular bacterial genome would be approximately 500 times less than the number of guesses needed to have all six numbers with probability one. The two situations correspond, for example, also to the two extreme cases in the search for protein structures starting from the open chain [3]: (i) Levinthal’s paradox illustrated by the golf course landscape, which is perfectly planar with only one hole in it, and where it is ultimately difficult to hit of the hole in a single stroke, and (ii) the funnel landscape where the ball runs down to the hole from everywhere. Needless to say, realistic landscapes for evolution are neither of the golf course nor of the smooth funnel type. At present, we do not know these landscapes sufficiently well to make a profound estimate but the improbability argument at the beginning of the paragraph is off the point.

SIMPLE RULES CAN LEAD TO COMPLEX AND SEEMINGLY PURPOSEFUL PROPERTIES

Statements of this kind seem to be commonplace for scholars of the sciences of complexity but an impressive illustration might nevertheless be worth the effort. I choose for this purpose a two-dimensional cellular automaton running on a chessboard of infinite (or finite) size known as John Conway’s game of life [4]. Cells are occupied or empty and there are only four rules determining pattern in the next generation: (i) Occupied cells with no or one occupied cell in the neighborhood become empty, (ii) occupied cells with two or three occupied cells in the neighborhood stay occupied, (iii) occupied cells with four or more occupied cells in the neighborhood are emptied, and (iv) empty cells with three occupied neigh-

I choose for this purpose a two-dimensional cellular automaton running on a chessboard of infinite (or finite) size known as John Conway’s game of life.

boring cells become occupied. Given the rules the unfolding of the cellular automaton in time is completely determined by its initial conditions, but nevertheless, an incredible richness of dynamical behavior results from the “game-of-life” rules. Some of these patterns are even suggestive of purposeful design. From one neither random nor fully ordered initial pattern a forever living periodical structure develops that emits small gliding motifs in one precisely defined direction.¹

¹The interested reader who shares some healthy skepticism with most nonspecialists is invited to download the program from the web page [4] and to play “gospo glider gun.” It is also recommended to make small variations in the initial con-

EVOLUTION OF BACTERIA CAN BE INVESTIGATED IN THE LABORATORY

Richard Lenski and his coworkers carried out a remarkable experiment: They studied and study the evolution of a population of *Escherichia coli* under controlled laboratory conditions and over several ten-thousands of generations [5]. Changes in genotype sequences appear and become fixed in the population as it adapts to the changed environmental conditions, clones of closely related individuals form and the formation of phylogenetic trees can be observed. The *Escherichia coli* evolution experiment has been continued over more than 10 years before one of the most exciting events happened (Lenski, R.E., private communication and lecture given at the Evolution Conference 2004, Fort Collins, CO): After 33,000 generations, 1 of 12 different colonies started spontaneously to utilize citrate in the medium (Citrate in the nutrition medium is used as a buffer to control pH). Although spontaneous mutations were often invoked to explain resistance of bacteria against antibiotics, here the colony was “caught with a smoking gun.” Interesting for our purpose here is that this innovation did happen under the constant conditions of a laboratory evolution experiment. In the past several people had declared evolution as nonscientific, because they thought it lacked the empirical component and therefore were not falsifiable. The bacteria experiments and evolution of molecules discussed in the next paragraph demonstrate that evolutionary biology has indeed also an experimental component and is an empirical scientific discipline.

ditions by adding and removing occupied cells. The result is reminiscent of mutations in nature: (i) Some changes are neutral in the sense that they give rise to the same dynamical pattern, (ii) some modify the pattern, and (iii) some develop quickly into a stationary pattern.

OPTIMIZATION AND ADAPTATION OCCUR IN ENSEMBLES OF MOLECULES

Starting in the 1960s [6] evolution experiments were performed with molecules that replicate in cell free media (For a description of the underlying processes by means of chemical reaction kinetics see [2]; for computer simulations see [7]). These *in vitro* evolution experiments have shown that the Darwinian mechanism is not dependent on the existence of cellular life; it works equally well with suitable molecules. Much later evolution experiments with molecules, in particular RNA and proteins, were also exploited in biotechnology to prepare molecules with predefined properties through variation and selection [8, 9]. One major finding of these studies is that RNA molecules called aptamers can be optimized to bind other molecules with affinities as strong as the strongest ones found in nature. The selection experiments in laboratory setups allow even for a distinction between rational design by an experimenter and production through variation and selection. In case the experiment is repeated under identical conditions, the results of the designed process would be unchanged and identical RNA sequences and structures would be found. The evolution experiment, however, would certainly yield different sequences and with high probability different structures with the same functional properties for which they were optimized. Reason for these differences is the enormous large number of possible solutions to a given problem that makes it very unlikely to obtain precisely the same result through variation and selection twice [7].

EVOLUTION OF COMPLEX ORGANS CAN BE TRACED AT THE MOLECULAR LEVEL

The eyes of vertebrates, cephalopods, or insects are often addressed as undeniable examples for creation by a designer. The conventional view in biology interpreted these three and several other eyes as independent evolutionary developments. Recent work in molecular genetics [10] has shown, however, that all known

forms of eyes have a common evolutionary origin and the same or very closely related genes control eye development in very different organisms. Moreover it seems that the common origin of the shared photosensitive molecule dates way back into prokaryotic life of the Precambrian. An interesting detail of the three eyes mentioned above concerns the connection of the photosensitive pigments with neurons. Evolution got it two times right, in the cephalopod and in the insect eye, where the light shines on one side of the retina and the neurons collect the pulses on the opposite side. In our vertebrate eye, however, the neurons leave at the same side where the light is received and therefore the bundle of neurons collected in the optic nerve has to pass the retina before it goes to the brain. The passage point is the so-called blind spot of the eye. This remarkable imperfection brings us to our last statement.

These *in vitro* evolution experiments have shown that the Darwinian mechanism is not dependent on the existence of cellular life; it works equally well with suitable molecules.

EVOLUTION BY VARIATION AND SELECTION IS TINKERING OR "BRICOLAGE"

Molecular genetics, in particular sequencing of whole genomes, has confirmed an early suggestion by François Jacob [11]: Most higher organisms, in particular animals, share almost all their genes, but the gene products are used several times in development and in the adult organism, and even for different purposes. Therefore, he concludes, evolution does not operate like an engineer but tinkers or performs bricolage. In order to provide a solution for a new task no real novelty is required on the molecular level. Instead the existing pieces are used, reassembled, and if necessary slightly modified. Now, more than 20 years after the "tinkering suggestion," we see Jacob's conjecture fulfilled almost everywhere in nature and

According to the principle of Ockham's razor, we have to stick to the simplest explanation in science.

the complex interrelation of multiply used parts is thought to be one, if not the most important, reason for increasing complexity in evolution [12].

What kind of conclusion can we draw from these six statements? Darwinian evolution, understood as the interplay between variations that are uncorrelated to their results and selection,² is an empirical scientific fact, a fact in the same class with the Copernican solar system, Newtonian mechanics, Einstein's universe or the world of quantum mechanics, and neither one hypothesis among others nor an ideology. The interpretation of observations in biology, as we understand it today, needs neither a plan nor does it provide obvious hints for an active designer. According to the principle of Ockham's razor, we have to stick to the simplest explanation in science. An obvious question, of course, is: How would a biology look like that could reveal traces of individual acts of design and thus calls for the action of a designer? A simple and somewhat naïve answer is: Multiple origins of the biosphere and individually optimized molecular machineries would more likely call for independent design. For me the overwhelming beauty of the biosphere is its diversity in form and function together with astonishing universality and conservatism when it comes to the molecular basis. This calls for an origin that is concordant with the laws of nature as exemplified in cosmology, physics, and chemistry.

²*It is necessary to mention here that we restricted this column to Darwinian evolution as addressed in the Cardinal's letter to the New York Times. There are periods in evolution, called the major transitions [13, 14], where we see other principles in operation. To discuss problems related to these steps in the evolution of the biosphere would deserve and require a 'Simply Complex' of its own.*

REFERENCES

1. Wigner, E. On the probability of the existence of a self-replicating unit. In: *The Logic of Personal Knowledge; Essays presented to Michael Polanyi on his seventieth birthday 11th March 1961*. Shils, E., Ed.; Free Press: Glencoe, IL, 1961.
2. Eigen, M. Self-organization of matter and the evolution of biological macromolecules. *Naturwissenschaften* 1971, 58, 465–523.
3. Dill, K.A.; Chan, H.S. From Levinthal to pathways to funnels. *Nat Struct Biol* 1997, 4, 10–19.
4. Martin, E. John Conway's Game of Life. Internet documentation and downloads: <http://www.bitstorm.org/gameoflife>.
5. Elena, S.F.; Lenski, R.E. Evolutionary experiments with microorganisms: The dynamics and genetic bases of adaptation. *Nat Rev Genet* 2003, 4, 457–469.
6. Spiegelman, S. An experimental approach to the experimental analysis of precellular evolution. *Quart Rev Biophys* 1971, 4, 213–253.
7. Schuster, P. Molecular insights into evolution of phenotypes. In: *Evolutionary Dynamics. Exploring the Interplay of Selection, Accident, Neutrality, and Function*. Crutchfield, J.P.; Schuster, P., Eds.; Oxford University Press: New York, 2003, pp 163–215.
8. Watts, A., Schwarz, G., Eds. Evolutionary biotechnology—From theory to experiment. *Biophys Chem* 1997, 66/2-3, 67–284.
9. Marshall, K.A.; Ellington, A.D. *In vitro* selection of RNA aptamers. *Methods Enzymol* 2000, 318, 193–214.
10. Gehring, W.J. The genetic control of eye development and its implications for the evolution of the various eye-types. *Int J Dev Biol* 2002, 46, 65–73. See also *Zoology* 2001, 104, 171–183.
11. Jacob, F. *The possible and the actual*. Pantheon Books: New York, 1982. See also *Evolutionary tinkering*. *Science* 1977, 196, 1161–1166.
12. Duboule, D.; Wilkins, A.S. The evolution of 'bricolage.' *Trends Genet* 1998, 14, 54–59.
13. Maynard Smith, J.; Szathmáry, E. *The major transitions in evolution*. W.H. Freeman: Oxford, 1995.
14. Schuster, P. How does complexity arise in evolution? *Complexity* 1996, 2/1, 22–30.