

Evolution vs. Design: Genetic Algorithms May Clarify the Controversy

MICHAEL LEVIN

*Department of Cytokine Biology, The Forsyth Institute, and Department of Craniofacial and Developmental Biology, Harvard School of Medicine, 140 The Fenway, Boston, MA 02115
e-mail: mlevin@forsyth.org*

Abstract—The dominant paradigm in biology today is Neo-Darwinism. This attempt to explain the origin of biological complexity through random changes coupled to selection has met with challenges from advocates of "design" who claim that this process is simply insufficient to result in the complexity we observe in the biosphere. Progress on this empirical question has been slow because the debate has been at the level of philosophical speculation and arguments over probability. It is simply not known whether or not random changes in the genome, coupled with selection, are sufficient to result in the rich biosphere of today. Here, I propose that both mainstream biologists and adherents of design hypotheses can profit from attention to Genetic Programming (GP)—an area of computer science with deep analogies for the question of biological evolution. The GP field is unique in that it provides a research program for beginning to empirically resolve the debate of design vs. Darwinian evolution. Recent progress in evolving complex computer programs shows that our intuition badly underestimates what can be accomplished by a "blind" evolutionary process. The degree of progress of the field of GP will enable insights into both the limits and the power of un-directed evolution.

Keywords: genetic algorithms — genetic programming—evolution—design

The incredible richness of the biosphere challenges scientists to explain the origin of today's complex plants and animals. Thus, biologists seek models of the kinds of processes that could account for the appearance of complex creatures well suited to their environments. Such models must address the forces underlying transitions from simple to more sophisticated organisms, and these models must also comment on the issue of whether or not such forces possess an inherent drive towards greater complexity or even specific design endpoints. Theories of this process predate modern biology, but currently the field is dominated by a synthesis of the great recent progress in biochemistry, molecular biology, and genetics with Darwinian evolution (Dawkins, 1987; Laszlo, 1987; Maynard Smith, 1975).

The classical "Darwinian" theory begins with three observations, all of which were known long before Darwin's day. These basic axioms are: A1) offspring resemble their parents more than they resemble unrelated individuals (i.e., traits are hereditary); A2) offspring are not always exactly like their parents (the transmission of characters occurs with high but imperfect fidelity); and A3)

resources (such as food, mates, territory, etc.) are limiting because of the exponential proliferation of organisms during times of plenty. The genius of Darwin was to realize (and support by painstaking observation) that these three facts, when joined together, may form a powerful system for explaining biological complexity. He argued that because of the intense competition for limiting resources, even small advantages lead to increased chances for the bearer to survive and leave offspring carrying the same advantages; thus, beneficial errors in hereditary transmission (rare though they may be) will accumulate and come to dominate the population over geological time scales. While simple organisms are usually at least as successful as complex ones, the relentless accumulation of beneficial traits thus drives upwards the overall complexity of the biosphere as organisms explore every possible way of staying alive.

The most fundamental aspect of modern Evolutionary Theory (ET), and the one which is sometimes challenged, is its insistence that the genetic changes that occur are not in any way *correlated with their consequences for the survival of the organism* (although they may not be precisely random, as some types of changes to genetic material occur more often than others); the changes are not teleological (do not occur with a purpose and are not aimed at any subsequent goal). The key is that, counter to older theories, events occurring to the individual (such as the giraffe stretching his neck as he reaches for higher leaves) do not affect the distribution of mutations that occur to that creature's offspring (will not result in offspring which have longer necks). This lack of teleology in genetic changes is the main feature of ET, which makes a striking empirical claim: that constrained by boundary conditions A1–A3, such uncorrelated genetic changes will over time result in creatures which are very complex and are incredibly well adapted to their environment.

The three axioms are individually true, and cannot rationally be denied. However, the main claim of ET is an empirical one, and is not obviously true or false: is random genetic change sufficient as a source of novelty to account for the observed complexity, or is it not? A number of lesser challenges to ET have been proposed, including non-traditional transfer of genetic material (Jablonka & Lamb, 1995; Margulis & Fester, 1991; Steele et al., 1998), and "order for free" from complexity theory (Ho & Fox, 1988; Ho & Saunders, 1984; Kauffman, 1993, 1995; Shapiro, 1999a, 1999b, 2002; Solé & Goodwin, 2000; Webster & Goodwin, 1996). Fascinating as these details are, none of them are major challenges because ET itself has no specific commitment to any genetic mechanism. What's important for ET is that the genetic change is not directed toward any specific outcome. This constraint is compatible with genetic operators other than simple mutation, such as the acquisition of genetic material from other creatures (such as the symbiosis observed in mitochondria, or virus-mediated gene transfer) and recombination (rearrangement of stretches of genetic material). Thus, these sorts of "non-Darwinian" mechanisms are not anomalous and represent perfectly mainstream science. More exotic proposals deriving teleology in genetic change from quantum physics have also been made (McFadden, 2001).

The major challenge for ET has come from advocates of the design hypothesis (Behe, 1996; Behe et al., 2000; Dembski, 2002, 2004a, 2004b; Dembski & Kushiner, 2001; Dembski & Ruse, 2004; Denton, 1986; Moreland, 1994; Sheldrake, 1981, 1988; Spetner, 1997). While mainstream biology mostly ignores advocates of design, it is not in fact true that one has to be "crazy or ignorant" (Dawkins, 1989) to ask for direct evidence to support the claim that evolutionary processes are indeed sufficient to provide the complexity we observe. Regardless of the personal motivations (religious or otherwise) of the various participants in this debate, two variations of the design hypothesis as such are scientific in structure. On the one hand, one may propose that mutations are not in fact random with respect to their effects on the organism. More strongly, one may doubt ET's claim that random genetic change is sufficient to account for complex life forms and propose the search for additional organizing principles. Even stronger claims, however (such as, "God did it"), leave the realm of scientific inquiry, but even the more reserved design hypotheses are anomalous in the sense that they are at odds with the direction of science as we know it.

This paper is an attempt to elevate the debate beyond philosophy. My intended audience comprises those interested in the scientific pursuit of the truth on this matter. This proposal will make no impact on those who read scripture in such a way as to tightly constrain the mechanism by which God's creation gave rise to living things, nor on those scientists for whom the sufficiency of random genetic change is an unassailable dogma. Although the debate among these camps has generated significant heat (insofar as it impacts public policy in education), it is now necessary to sharpen the discussion to abstract from hand-waving arguments and explore ways in which empirical data can help distinguish between the two views.

A compromise view can be tempting: maybe God subtly tweaks mutations by orchestrating chemical changes in DNA in concert with some grand plan? At first blush, this shouldn't offend the biologists since it is compatible with whatever mechanisms they discover to be operating. The reason why this is unsatisfactory to modern science is instructive and important. The striking power of Darwinian Evolution is in its minimalism—it proposes to explain all of biological complexity without recourse to an even more complex entity (a designer). This is Occam's razor at its finest, and is in perfect consilience with science's (strikingly successful) attempt to explain phenomena by reduction to simple underpinnings (Dennett, 1995; Wilson, 1998). Thus, the commitment of most scientists to ET is not based just on specific evidence for this model, but is also driven by the metaphysical commitment to reductive physicalism.

ET's main thrust is an empirical claim, and is in fact a promissory note. Biologists can almost never specify fitness in advance—those animals with the highest fitness survive best (a tautology)—but it is often not clear what in fact will confer highest fitness (especially when one tries to consider the costs of various body features). Also, the main claim of evolution cannot be tested by direct experiment on tractable time-scales; moreover, the genetic changes

produced in labs do not give rise to a more successful species—they are almost without exception deleterious and do not induce the kind of macroscopic, coordinated changes we associate with different phyla.

ET is a scientific theory that postulates that genetic change is random with respect to outcome. It therefore holds that some sort of plausible evolutionary story must be available for every biological feature, whether or not we know the details of each story. The theory is capable of making predictions that can be tested, like other scientific theories, by observation if not always by experiment. ET has had considerable success in biology and biomedicine, which cannot, as yet, be said for the design hypothesis.

Despite what most biologists and educated laymen think, the onus of proving the case is really split. Evolutionists have to show that ET is in fact sufficient for generating the observed complexity. Similarly, adherents of design have to propose an alternative model and/or a research program that is useful in moving science forward. The debate to date can basically be encapsulated thus. Some advocate of design proposes a specific element of the organism which is "an example of irreducible complexity which could never arise by small steps" (Behe, 1996). Evolutionists respond, "It had to arise that way, therefore we're sure that someday we'll find out exactly what those steps were, and we'll have a causal chain where each step is, by itself, advantageous." Aside from the search for the perfect example of irreducible complexity, there are also a number of critiques of evolution from the perspective of metaphysics. All of these, although interesting and perhaps instructive, are ultimately cheap claims to make without specific proof as to whether evolution can or cannot happen by the non-teleological mechanisms of ET.

The debate can be refocused along practical lines that provide an empirical way to answer this question. The field which can enrich this debate is Genetic Programming (Back, 1995; Fogel, 1998; Kinnear, 1994; Koza, 1992, 1999; Miettinen, 1999). Genetic Programming (GP), also known as Genetic Algorithms and Evolutionary Programming, is a special case of the field of Artificial Life—exploring the properties of complex systems through computer simulation (Adami, 1998; Langton, 1995). Rather than designing computer programs to accomplish specific ends as is done in conventional programming, in GP an evolutionary paradigm is used. The process starts with a population of randomly created programs (random strings of instructions). These are evaluated with respect to their ability to perform the desired task (e.g., fit a curve to a set of numbers, or balance a robot as it climbs stairs). The top performers, even though they are pitiful at first, are kept, and the next round's population consists of mutated and recombined versions of the fittest. The process continues until a desired level of performance is reached. A number of bells and whistles can be superimposed on this basic process to improve its efficiency in finding a program of sufficient fitness (e.g., modeling recombination or other rearrangements of whole sections of the genome, co-evolution of several competing "species" in the same artificial world, etc.).

Upon hearing such a plan, anyone who has ever struggled to write a working computer program will have the same reaction as would Paley (1814), if confronted with a watch in the forest and told that it came about by random movement of metal. It seems absolutely ludicrous to think that a satisfactory computer program can arise "by accident"; however, it works. It is indeed possible to obtain useful programs in this fashion, and sometimes, programs performing tasks that had resisted the development of algorithms by specific design (e.g., programs which distinguish male faces from female faces). This is a crucial point: it shows us that *our initial, basic intuitions about what kind of complexity can and cannot arise through evolutionary methods are simply not well calibrated*. Analogously to the way our brains, optimized for medium-sized objects moving at slow speeds, do not immediately grasp the reality revealed by relativity theory and quantum mechanics, our basic expectation about what can occur through an evolutionary process is too low.

GP illustrates a number of other important aspects of evolutionary theory. As in ET, the whole process can only get off the ground once a self-replicating unit and a system of heredity exist. In EP, this is provided explicitly as part of the framework within which the programs compete. The origin of the self-replicating unit, which is likely to require a considerable minimal complexity, is unknown. This of course is of key importance to critics of ET. Another analogy is the rate of progress in the field of EP. While it (rightly) generated considerable interest and a fury of theoretical and practical research, one could argue that progress has slowed considerably. The scaling problem has not been solved: there seems to be a slump in generating solutions to big, real-world problems. This may be relevant to the observation that genetic change via mutation is well suited to tuning small differences in traits but it is harder to see how major beneficial innovations may arise. Recent attempts to overcome these problems have involved the addition of other genetic operators (e.g., recombination) in GP algorithms. GP also provides an illustration of the non-optimal nature of problem solving by evolutionary processes. Supporters of ET commonly point to the fact that biological systems are cobbled together by re-using existing parts and by satisficing and do not exhibit the kind of optimal and clean design that might be expected from a "designer". Successful programs developed by GP share this feature, often including extremely convoluted information paths.

My proposal is that both advocates of design and mainstream biologists pay attention to, support, and draw insights from the developing field of GP. This is a rich literature and body of work that is not commonly known to biologists, and does not seem to feature at all in arguments about evolution from either side. Deep insights are available to both camps here. While a number of biologists have attempted computer simulations of the evolution of specific structures such as the eye (Nilsson & Pelger, 1994), the most important advances will come from an analysis of how generalized complexity and problem-solving can be obtained from evolutionary processes. Examination of successful GP cases will enable both sides to sharpen their tools for the detection of design vs. apparent

design, and develop algorithms for the objective analysis of "optimality". These analytical paradigms can then bring significant novel insight to the evolution debate as they are applied to real biological systems.

What is also needed is a solution to the "slump" in the GP field. If GP can be shown to effectively generate extremely complex programs suited to arbitrary real-world problems, it will be powerful evidence against an upper bound to the complexity that can indeed be generated by such a process. The most promising areas for making such advances is the introduction within GP paradigms of self-organizing properties of networks (Kauffman, 1993), and of an analogy to embryonic development—the layer which links genetic material to physical form and function (Gerhart & Kirschner, 1997; Hall, 1999; Raff, 1996; Raff & Kaufman, 1991; Raff & Raff, 1987; Salthe, 1993). Most arguments about evolution neglect the fact that genes do not encode traits. Genes encode the shape of molecular building blocks, which, during embryonic development, interact according to mathematical and physical principles governing self-organizing systems to build a complex organism. The various traits of this organism arise epiphenomenally from the interaction of the building blocks created by the genome; thus, an appreciation of what sorts of structures and physiological functions can arise from changes in the genome must take into account the properties of embryonic morphogenesis. It is only through development that the genome builds the phenotype, upon which selection eventually acts.

This work will be extremely useful for evolutionary biologists because it will be able to provide a direct example of complexity arising *de novo*, as well as allow them to study the properties of ET in a tractable time frame in a medium in which all aspects can be controlled and observed by the user. Advocates of design will benefit by increased attention to GP because it gives them a way to propose a direct and specific challenge to evolutionists to cash in their promissory note. More specifically, the successes and failures of GP approaches can be instructive regarding areas where evolutionary processes may or may not be successful, allowing them to focus their analyses of living systems more appropriately.

References

- Adami, C. (1998). *Introduction to Artificial Life*. Santa Clara, CA: Telos/Springer-Verlag.
- Back, T. (1995). *Evolutionary Algorithms in Theory and Practice: Evolution Strategies, Evolutionary Programming, Genetic Algorithms*. Oxford University Press.
- Behe, M. J. (1996). *Darwin's Black Box: The Biochemical Challenge to Evolution*. Free Press.
- Behe, M. J., Dembski, W. A., Meyer, S. C., & Wethersfield Institute. (2000). *Science and Evidence for Design in the Universe. Papers Presented at a Conference Sponsored by the Wethersfield Institute, New York City, September 25, 1999*. San Francisco: Ignatius Press.
- Dawkins, R. (1987). *The Blind Watchmaker: Why the Evidence of Evolution Reveals a Universe Without Design*. Norton.
- Dawkins, R. (1989). Put your money on evolution. *New York Times*, 9 April 1989, section VII, pp. 35.
- Dembski, W. A. (2002). *No Free Lunch: Why Specified Complexity Cannot Be Purchased Without Intelligence*. Rowman & Littlefield.
- Dembski, W. A. (2004a). *The Design Revolution: Answering the Toughest Questions About Intelligent Design*. Downers Grove, IL: InterVarsity Press.

- Dembski, W. A. (2004b). *Uncommon Dissent: Intellectuals Who Find Darwinism Unconvincing*. Wilmington, DE: ISI Books.
- Dembski, W. A., & Kushiner, J. M. (2001). *Signs of Intelligence: Understanding Intelligent Design*. Grand Rapids, MI: Brazos Press.
- Dembski, W. A., & Ruse, M. (2004). *Debating Design: From Darwin to DNA*. Cambridge University Press.
- Dennett, D. C. (1995). *Darwin's Dangerous Idea: Evolution and the Meanings of Life*. Simon & Schuster.
- Denton, M. (1986). *Evolution: A Theory in Crisis*. Bethesda, MD: Adler & Adler.
- Fogel, D. B. (1998). *Evolutionary Computation: The Fossil Record*. New York: IEEE Press.
- Gerhart, J., & Kirschner, M. (1997). *Cells, Embryos, and Evolution: Toward a Cellular and Developmental Understanding of Phenotypic Variation and Evolutionary Adaptability*. Blackwell Science.
- Hall, B. K. (1999). *Evolutionary Developmental Biology*. Kluwer.
- Ho, M.-W., & Fox, S. W. (1988). *Evolutionary Processes and Metaphors*. Wiley.
- Ho, M.-W., & Saunders, P. T. (1984). *Beyond Neo-Darwinism: An Introduction to the New Evolutionary Paradigm*. Academic Press.
- Jablonka, E., & Lamb, M. J. (1995). *Epigenetic Inheritance and Evolution: The Lamarckian Dimension*. Oxford University Press.
- Kauffman, S. (1993). *The Origins of Order: Self-organization and Selection in Evolution*. Oxford University Press.
- Kauffman, S. A. (1995). *At Home in the Universe: The Search for Laws of Self-Organization and Complexity*. Oxford University Press.
- Kinney, K. E. (1994). *Advances in Genetic Programming*. MIT Press.
- Koza, J. R. (1992). *Genetic Programming: On the Programming of Computers by Means of Natural Selection*. MIT Press.
- Koza, J. R. (1999). *Genetic Programming III: Darwinian Invention and Problem Solving*. San Francisco: Morgan Kaufmann.
- Langton, C. G. (1995). *Artificial Life: An Overview*. MIT Press.
- Laszlo, E. (1987). *Evolution: The Grand Synthesis*. Boston: New Science Library.
- Margulis, L., & Fester, R. (1991). *Symbiosis as a Source of Evolutionary Innovation: Speciation and Morphogenesis*. MIT Press.
- Maynard Smith, J. (1975). *The Theory of Evolution*. Penguin.
- McFadden, J. (2001). *Quantum Evolution*. Norton.
- Miettinen, K. (1999). *Evolutionary Algorithms in Engineering and Computer Science: Recent Advances in Genetic Algorithms, Evolution Strategies, Evolutionary Programming, Genetic Programming, and Industrial Applications*. Wiley.
- Moreland, J. P. (1994). *The Creation Hypothesis: Scientific Evidence for an Intelligent Designer*. Downers Grove, IL: InterVarsity Press.
- Nilsson, D. E., & Pelger, S. (1994). A pessimistic estimate of the time required for an eye to evolve. *Proceedings of the Royal Society of London. Series B. Biological Sciences*, 256, 53–58.
- Paley, W. (1814). *Natural Theology: Or, Evidences of the Existence and Attributes of the Deity, Collected from the Appearances of Nature*. Philadelphia: M. Thomas.
- Raff, R. A. (1996). *The Shape of Life: Genes, Development, and the Evolution of Animal Form*. University of Chicago Press.
- Raff, R. A., & Kaufman, T. C. (1991). *Embryos, Genes, and Evolution: The Developmental-Genetic Basis of Evolutionary Change*. Indiana University Press.
- Raff, R. A., & Raff, E. C. (1987). *Development as an Evolutionary Process: Proceedings of a Meeting Held at the Marine Biological Laboratory in Woods Hole, Massachusetts, August 23 and 24, 1985*. New York: A. R. Liss.
- Salthe, S. N. (1993). *Development and Evolution: Complexity and Change in Biology*. MIT Press.
- Shapiro, J. A. (1999a). Genome system architecture and natural genetic engineering in evolution. *Annals of the New York Academy of Science*, 870, 23–35.
- Shapiro, J. A. (1999b). Transposable elements as the key to a 21st century view of evolution. *Genetica*, 107, 171–179.
- Shapiro, J. A. (2002). Genome organization and reorganization in evolution: Formatting for computation and function. *Annals of the New York Academy of Science*, 981, 111–134.
- Sheldrake, R. (1981). *A New Science of Life: The Hypothesis of Formative Causation*. J. P. Tarcher.

- Sheldrake, R. (1988). *The Presence of the Past: Morphic Resonance and the Habits of Nature*. New York: Times Books.
- Solé, R. V., & Goodwin, B. C. (2000). *Signs of Life: How Complexity Pervades Biology*. Basic Books.
- Spetner, L. M. (1997). *Not by Chance! Shattering the Modern Theory of Evolution*. New York: Judaica Press.
- Steele, E. J., Lindley, R. A., & Blanden, R. V. (1998). *Lamarck's Signature: How Retrogenes are Changing Darwin's Natural Selection Paradigm*. Perseus Books.
- Webster, G., & Goodwin, B. C. (1996). *Form and Transformation: Generative and Relational Principles in Biology*. Cambridge University Press.
- Wilson, E. O. (1998). *Consilience: The Unity of Knowledge*. Knopf.