The Nature of Evolution

David L. Alles

Western Washington University

e-mail: alles@biol.wwu.edu

Alles, D. L. (2005). The Nature of Evolution. *The American Biology Teacher*, Vol. 67, No. 1(Jan), 7-10.

What is evolution?

Evolution, as the term is commonly used, refers to scientific theories about life on Earth. But in the simplest of terms evolution is a process of change. In this paper I will define the process of evolution in universal terms taken from the physical sciences and the philosophy of science. Doing so shows that evolution is not confined to organic systems, such as life on Earth, but is, instead, a general characteristic of the universe itself. To demonstrate this I will explore the historical nature of change in our universe, change produced by the operation of dynamic processes at the smallest and largest of scales. I will start this exploration, appropriately enough, at the beginning of our universe as an historical system.

Historical Systems

If we survey modern astronomy, and its sub-disciplines cosmology and astrophysics, what large scale fundamental features of our universe become apparent? First of all our universe had a beginning. Results from NASA's Wilkinson Microwave Anisotropy Probe (the WMAP project) have placed the beginning of the universe at 13.7 billion years ago (WMAP/NASA, 2003). Even ten years ago careful cosmologists would offer only that the universe was somewhere between 10 and 20 billion years old. Today astronomers confidently tell us that the 13.7 billion year old figure has a margin of error of only just over 1%. The WMAP study has also increased the resolution of the early events in the universe offering an estimate of 379,000 years after the beginning of the universe (the "Big Bang") for the decoupling of matter and energy that produced the cosmic microwave background radiation, and placing the formation of the first stars at approximately 200 million years after the Big Bang. The study has also produced an estimate for the rate of expansion of the universe, as defined by the Hubble constant (Ho) of Ho = 71 kilometers/second/Mega-parsec, with a margin of error of about 5%. It has also verified that the geometry of the universe is flat and, as a result, the universe will expand forever. Put as succinctly as possible, the universe is expanding and fundamentally changing as time passes and will continue to do so forever. The concept of historical systems is any well defined system that has a cumulative, changing history (Alles, 1998). Our universe is an historical system with a beginning, cumulative change through time, and a potentially intelligible end.

Absolute Change

If you look at the largest scale of both time and space in the history of the universe, it's clear that the universe has changed. If nothing else the universe has expanded and continues to expand. But to see the absolute nature of change in our universe we must look at it as defined by Einstein's theory of general relativity. In general relativity the universe is an entity called space-time that is created by the distribution of energy and matter. If we understand that all events produce changes in the energy-matter distribution of the universe, then, no matter how small, all events produce changes in the very fabric of the universe. In Steven Hawking's words:

> "Space and time are dynamic quantities: when a body moves, or a force acts, it affects the curvature of space and time and in turn the structure of space-time affects the way in which bodies move and forces act. Space and time not only affect but also are affected by everything that happens in the universe."
> —Hawking, 1988, 33

What this means is that, in an absolute sense, every instant the universe changes irreversibly. Thus every moment in the history of the universe is unique. What we need to recognize from this, in order to understand the universal nature of evolution, is that our universe is a dynamic place that is constantly changing irreversibly on the largest and smallest of scales.

Natural Processes and Initial Conditions

To understand the implications of constant, irreversible change in our universe, we must distinguish between natural processes, or "how the universe works", and initial conditions, the physical state of the universe at any given instant of time or "how the universe is".

A biological example of "how the universe works" would be the life cycle of organisms such as ourselves. We are born. We grow and develop. We reproduce, then grow old and die. This is one of the central processes of life, and out of necessity, we are all acquainted with it.

"How the universe is" is subtly different, and represents the historical outcome of the operation of natural processes. Using the example of the life cycle, our view of "how the universe is" would be the history of a specific life cycle. Charles Darwin was born in 1809, graduated from Cambridge University in 1831, married soon after his return to England in 1836, had eight children, published *On the Origin of Species* in 1859, grew old, and died in 1882. This is a specific life cycle, unique in the history of life on Earth, and never to be repeated again.

Initial conditions, or "how the universe is", describe the historically contingent state of the universe as we find it. On the other hand, the natural processes at work that produce initial states, remain unchanged. In other words, a process, as in the example of the life cycle, is a sequenced set of changes that transforms something from one state to another, but is not itself changed.

Using this definition of process, is evolution, then, just a process of change? The answer is yes, it is. What is still missing, however, is a fundamental description of what the process of evolution is.

Natural Algorithms

The "process of evolution", in reality, describes a class of related, natural algorithms. What is an algorithm? The philosopher of science Daniel Dennett has analyzed this question at length in his book *Darwin's Dangerous Idea* (1995), and provides the following answer.

By Dennett's definition an algorithm has:

- *substrate neutrality*: The power of the process is due to its *logical* structure, not the properties of the materials involved in its particular occurrence.

- *underlying mindlessness*: Although the overall organization of the process may yield brilliant results, each constituent step, as well as the transition between steps, is utterly simple.

- *guaranteed results*: Whatever it is that an algorithm does, it always does it. If it occurs without misstep, an algorithm is a foolproof recipe.

This does not mean that an algorithm must always produce the same result. Because of absolute change, algorithms of natural processes always operate on a unique set of initial conditions, that, in turn, produce historically contingent outcomes. What evolutionary algorithms are a foolproof recipe for is cumulative change, where each outcome of the algorithmic process operating on an historical system is different from the last. What is guaranteed is change itself.

> "What Darwin discovered was not really one algorithm but, rather, a large class of related algorithms that he had no clear way to distinguish. We can now reformulate his fundamental idea as follows: Life on Earth has been generated over billions of years in a single branching tree—the Tree of Life—by one [evolutionary] algorithmic process or another."—Dennett 1995, 50-51

What Dennett doesn't clarify until later in his book is that, as it concerns evolution in natural systems, we are talking about *natural* algorithms—algorithmic processes in nature that have the above characteristics but do not have an end directed goal. They exist and operate but they are not algorithms for producing particular outcomes. They have no teleological purpose, no "final cause". This is Aristotle's fourth division of causality, and it is final not in the temporal sense of coming last, but in the Latin meaning of ultimate purpose. Natural algorithms are distinct from *constructed* algorithms—algorithms that have been created by humans to produce particular outcomes as in mathematics and computers.

Evolution as a Fundamental Process in our Universe

Constant, irreversible change in our universe means that as time flows forward the initial conditions in the present will always be different for the operation of natural algorithms. What must be added to this to describe evolutionary algorithms is an historical substrate upon which the process operates to produce cumulative change. In the universe at large that historical substrate is the universe itself. Evolutionary algorithms, because of their substrate neutrality, are not restricted to organic systems. Our universe has evolved through time. All stars evolve. And depending on their size and local environment, they evolve in different ways with different outcomes. Each star is unique in itself. Solar systems evolve along with their central stars. Planets evolve. The planet Earth has evolved in concert with the evolution of life. Our atmosphere, the very air we breathe has evolved in an intricate dance between life and inanimate molecules of carbon dioxide and oxygen.

Using the term "evolution" in this sense is not metaphorical. All evolutionary algorithms share certain characteristics in common. And it is the shared logic of these characteristics, along with substrate neutrality, that justifies the claim that evolution is not unique to living systems.

Cause and Effect in Closed Systems

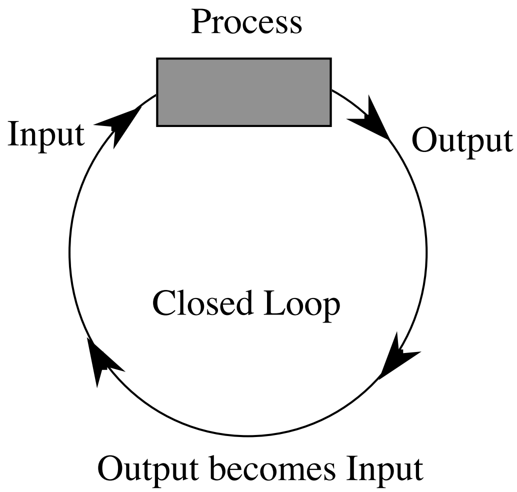
What characteristics, then, are common to all natural, evolutionary algorithms that makes them variations on a single theme? The answer takes us back to the fundamental features of our universe. The universe in not only an historical system, it is also a closed system.

One of the basic assumptions of science is that our universe is, by definition, all that there is. This means that all of the causes that produce effects in the universe are within one system. If science were to assume, instead, that causes could come from outside our universe and produce effects within it, it would then be impossible to make scientific predictions or construct scientific explanations. This is because there would be no way of telling whether a phenomenon was caused from without or within. You simple can't have it both ways. You either operate under the assumption that the universe is a closed system or you give up trying to do science (Pennock, 1999).

The implications of this when coupled to the historical nature of our universe are staggering. What it means is that cause and effect in the universe exists in a closed causal loop where the initial conditions upon which a process can operate are always the historical result of the last cycle of the process. In other words, the output of the process becomes the only possible input for the next round of the process (see Figure 1).

Figure 1:

Cause and Effect in a Closed System



This definition of a closed system can be modified by saying that it is possible to define a system as historical if it is in some way "effectively" closed. In this way it can be seen that life on Earth is a closed system, while at the same time acknowledging that there is external input to the system in the form of energy from the Sun and an occasional meteorite. Life on Earth is a "closed" system in one central characteristic—after its origin, life can only come from life. The process of life that is closed is reproduction. The genetic process of reproduction forms an unbroken physical link from the first organisms on Earth to life today, and, in this, it is a closed system. It is the historical substrate of the DNA molecule itself that the evolutionary algorithm of life operates on to produce cumulative change.

To illustrate this, if I substitute gene pool for output and input in Figure 1, and evolution by natural selection for process, then a description of the closed system of genetics would read: The gene pool produced by the operation of natural processes, such as natural selection, acting on the last generation of a given species is the only available genetic information that can be passed on to the next generation of that species and so on throughout time. The effect of repeating this process through time produces cumulative change in the historical substrate of genetics, or in a single word, it evolves.

As unlikely as it may seem, the process of star formation also exists in a closed casual loop. The first stars were formed from the primordial hydrogen and helium gas produced by the Big Bang and almost nothing else. There were no elements heavier than helium available in significant quantities. But with the evolutionary life and death of the first stars, heavier elements were formed from hydrogen and helium by nucleosynthesis in the center of stars and by the supernova deaths of massive stars. The clouds of gas from which the second generation of stars formed were then enriched with heavy elements. Our Sun is considered to be a third generation star and the cloud of gas and dust from which it formed was enriched even further with heavy elements. Heavy elements such as carbon, oxygen, silicon, aluminum, sulfur, nickel, iron and many more were now available to form stony planets. In this case the historical substrate that the evolutionary algorithm of star formation operated on was the mixture of primordial gases and heavy elements that were produced by past generations of stars. And it is from this evolutionary process that a new phenomena arose, the formation of stony planets like our Earth.

What is evolution?

Evolution is a class of natural algorithms, a type of causal relationship that produces cumulative change in historical systems. Evolutionary processes, including the evolution of life on Earth, are a fundamental characteristic of our universe.

One of the negative effects of the religious controversy in America over evolution may be a disinclination by the advocates of evolution to publicly explore its underlying nature (Pennock, 1999). This is extremely unfortunate because, as I have tried to show in this paper, rather than showing any weakness, an examination of evolution's fundamental nature not only serves to strengthen the evidence of its central importance to biology, but to all of science.

References

Alles, D. L. (1998). *Essays on the Nature of Causality*. http://fire.biol.wwu.edu/trent/alles/CausalityEssays.pdf . Retrieved 1/6/05.

Dennett, D. C. (1995). *Darwin's Dangerous Idea: Evolution and the Meanings of Life*. New York: Simon & Schuster.

Hawking, S. W. (1988). *A Brief History of Time*. New York: Bantam Books.

Pennock, R. T. (1999). *Tower of Babel: The Evidence against the New Creationism*. Cambridge, MA: MIT Press.

WMAP / NASA (2003). The First Detailed Full Sky Picture of the Oldest Light in the Universe. http://map.gsfc.nasa.gov/m_mm.html. Retrieved 1/6/05.

For other papers by David L. Alles go to:

http://fire.biol.wwu.edu/trent/alles/papersindex.html

For Alles Biology Home Page go to:

http://fire.biol.wwu.edu/trent/alles/index.html