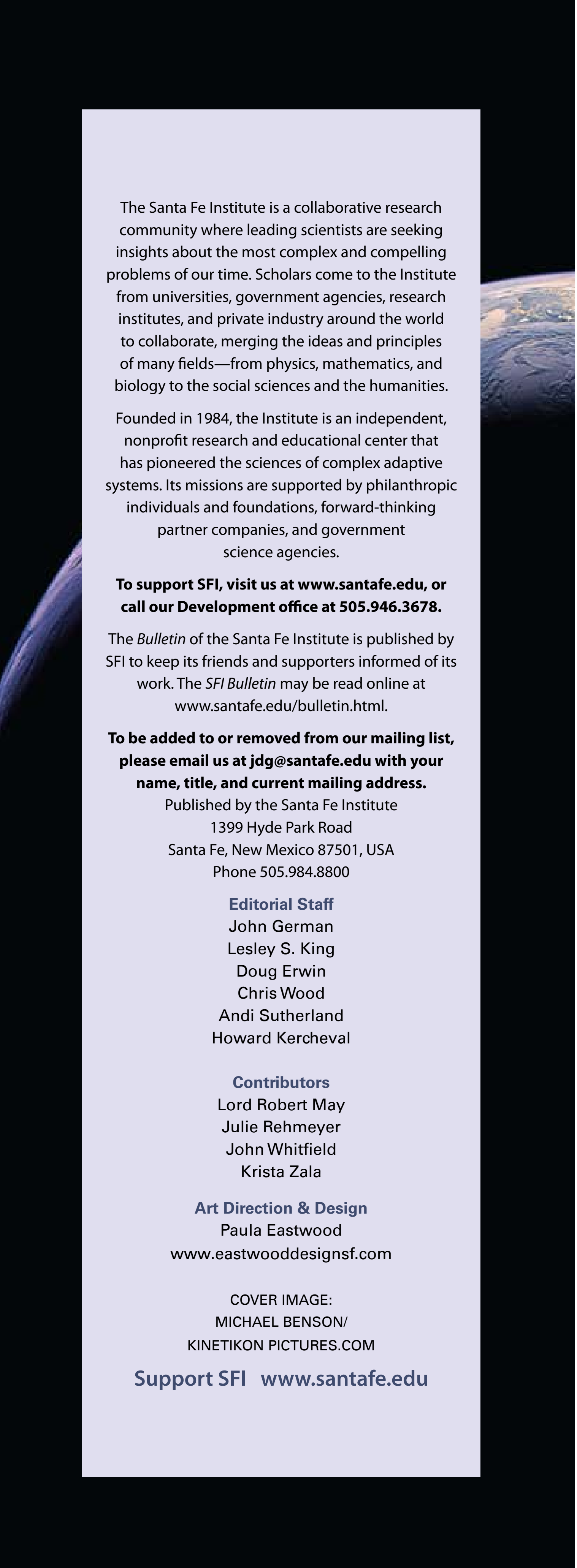

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Time, Chance and the Laws of History

BY DOUGLAS H. ERWIN
Chair of the Faculty

Perhaps the greatest challenge for the study of complex adaptive systems lies in the historical fields of natural science, whether astronomy, geology, evolutionary biology, paleontology, or archaeology. In each of these fields, experimental approaches are limited, studying modern systems may not provide much insight into processes in the distant past, and chance (contingency) often plays an important role. This tension between the role of chance and the search for regular patterns that underlie historical processes is also found in a number of social and behavioral sciences, where the SFI community has been increasingly active. Economics and historical linguistics have long had a home at SFI, but efforts in behavioral economics, anthropology, sociology, and even history and law are more recent.

History has been described as "one damn thing after another." Good historians have always tried to identify more general patterns and processes from the mass of detail, and the same is true in the historical natural and social sciences. Some have a much easier task than others. Astronomy, for example, draws on the foundation of physics, the assumption (well-verified, but still an assumption) that the life span of elemental particles and the nature of physical laws have remained constant through time and space. Because the nature of the components of astronomical objects is fixed and subject to unvarying physical laws, physicists are confident they understand the underlying mechanisms of the system. This is true no matter how complex the historical evolution of a galaxy, how complex the system, and how difficult the prospect of modeling: for example, the interactions between galaxies. (There is also, of course, the small matter of dark energy.) Difficulties in forecasting the dynamics of a single planetary system within a galaxy do not undermine our fundamental understanding of a galaxy, any more than

How do we approach systems in which the laws themselves may be changing through time?

the inability to predict when a large earthquake will hit San Francisco undermines seismology.

In the case of most historical disciplines, the situation is more challenging, for five reasons. First, when generalizations exist, they rarely have the force or sweep of the laws of physics. Darwin's law of natural selection predicts the future change in gene frequencies of information-carrying material with variation. However, the complex mapping between genotype and the resulting phenotype means that predicting the course of selection may provide little insight into evolutionary dynamics. Evolutionary theory is largely an ahistorical theory about a historical discipline. Generalizations of greater scope may yet be identified, of course, but perhaps only by addressing more forthrightly this historical nature of these systems.

Second, the variety of actors and the variety of their interactions vastly swamps that of simpler physical systems. Identifying causal "laws" may thus require simplifications that render irrelevant the whole enterprise. The tensions between the assumptions of rational expectations in economics and the findings of behavioral economics are a case in point.

Contingency, or chance, is a third challenge. In his book about the exquisite 505 million-year-old fossils of the Burgess Shale and the explosion of animal diversity, the late Stephen Jay Gould famously argued that if we were able to redo the early history of animals, different groups might succeed. Perhaps the now virtually unknown priapulids (marine, mud-inhabiting, unsegmented worms) would be more common than annelids (earthworms and their allies) and arthropods would be a forgotten diversion. Many examples of the contingent success or failure of different clades (biological groups) have since been identified, and they challenge the belief that a study of patterns of change can yield a general understanding of process.

The fourth challenge is really an extension of contingency; the conscious behavior of components of many evolving systems can change the rules of the game, or at least some of them, some of the time. Each time financial analysts identify some property of a market, their drive to exploit it generally eliminates the arbitrage (or trading) potential (at a speed determined by the efficiency of the market). As conscious actions alter the interactions between the agents, any model requires learning.

Finally, unlike many physical laws, the generalities of biology, economics, and the human sciences may themselves evolve over time. Indeed one of the most exciting areas in modern evolutionary biology is identifying how the kinds of genetic and developmental variations have changed over time spans of hundreds of millions of years. These discoveries, made by comparative studies of living animals, raise questions about the utility of experimental manipulations of living species. If the nature of available evolutionary mutations has changed over time, then the range of evolutionary possibilities has changed as well. In the arena of technology we know this is true: Personal computers were an impossible technology in the Renaissance, or even in 1950.

These challenges do not mean that we cannot study complex adaptive systems in deep time. Rather, they provide us an exciting opportunity to extend the approaches pioneered at SFI over the past few decades, and to

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By exploring underlying complex interactions and forces of evolution, researchers formulate new understandings of the diversification of life during the Cambrian explosion 540 million years ago.

develop new tools and approaches. This is the case with that fifth, and perhaps greatest, challenge from my list: How do we approach systems in which the laws themselves may be changing through time, particularly if the conditions today provide only limited information about the rules applicable in the past (or, of course in the future)? In my field of geology, this problem was initially articulated by Charles Lyell in the 1830s and has been incorporated in the adage drilled into geology students ever since: “The present is the key to the past.” But even Lyell’s colleagues (with the surprising exception of Charles Darwin) did not believe him.

There are several problems with Lyell’s perspective. Chief among these are that the present is really only a hypothesis about how the past works, and the range of mechanisms may be far greater than the limited sample size captured by modern scientific studies. Warm polar climates, deep oceans rich in sulfur and iron, or meteorites falling out of the sky, to cite a few recent discoveries, could never be imagined by Lyell. Empirical studies, and an open mind, can address this problem (good students, always sure their advisors are out of date, if not verging on senility, also help).

The SFI scientific community has been confronting these challenges with increasing vigor over the past few years. Some of these efforts are chronicled in this issue. For example, SFI’s Harold Morowitz and Eric Smith and their colleagues have generated a new approach to studies in the origin of life with their research on the evolution of metabolic networks. This is particularly relevant to the preceding discussion, because one vital implication of their work is that there may have been little scope for contingency in the evolution of these networks. If they are right, this, of course, suggests that carbon-based life forms elsewhere in the universe may have been constrained to similar metabolic pathways. This work exemplifies one of the strengths of SFI in addressing issues over time: Whether in evolution or economics, in many cases we will approach these problems from the perspective of how systems evolve. ◀