

FRACTALS

Parts That Reflect the Whole

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THOSE WHO KNOW THE SANTA FE INSTITUTE know we concern ourselves, on a theoretical level, with the often-unseen structures, patterns, and connections in complex adaptive systems. This focus on the underlying nature of things demands that we avoid the temptations of immediate, tangible outcomes.

Yet, in the 18 months since I arrived as SFI's President, I have witnessed substantial, and expanding, appreciation for the

Institute's science, not only among scientists but among policy makers and the public as well. Why? Because, I believe, the science of complex systems is the most productive way to understand our world, which grows more complex every day.

The pages of the *SFI Bulletin* highlight some of the ways complex systems science is making sense of relevant problems in the world around us. Each requires a transdisciplinary approach in which the tools of physics, the natural sciences, the social sciences, and the humanities all contribute. This SFI way of thinking—of doing science—and of addressing complex systems, has explanatory power across the realm of human experience. Inevitably, from this process emerges very real outcomes.

—**Jerry Sabloff**, *President of the Santa Fe Institute*

External Professor **JOHN GEANAKOPLIS** argued in a paper released in August 2010 by the Federal Reserve Bank of New York that in moments of financial crisis, central banks should lend at more generous terms than the market. This would break the self-reinforcing increase in collateral requirements that can result from a market shock—a phenomenon he has termed the “leverage cycle.”

During SFI's 2010 Ulam Lecture series in September, External Professor **Mark Newman** highlighted the emerging field of network science and showed how networks are illuminating never-before-seen relationships and patterns in society and the world.

External Professor **Dirk Helbing** and collaborators modeled traffic flow and found that self-organizing traffic lights that communicate and make decisions in coordination with other intersections could significantly reduce city traffic congestion.

External Professor **Bette Korber** and Professor **Tanmoy Bhattacharya**, both researchers at Los Alamos National Laboratory, are part of an international team preparing for the first human trial of a new kind of HIV vaccine they helped design using computational models. The candidate “mosaic” vaccine employs many sets of synthetic, computer-generated sequences of proteins to prompt the immune system to respond to a wide variety of circulating HIV strains.

Despite 100 million years of evolutionary divergence, three lineages of mammals—placentals (wombed mammals), marsupials (pouched mammals), and monotremes (egg-laying mammals)—all allocate the same proportional amount of energy to reproduction and offspring development, concluded a study led by Postdoctoral Fellow **Marcus Hamilton**. The work supports the notion that many properties of living things change in mathematically predictable ways with organisms' body sizes—a phenomenon known as allometric scaling.

External Professor and Science Board member **Melanie Mitchell's** book *Complexity: A Guided Tour* (Oxford University Press, 2009) received the Phi Beta Kappa Society's 2010 Book Award in Science. The award recognizes outstanding contributions by scientists to the literature of science.

Professor **SAM BOWLES** and External Professors **HERB GINTIS** and **ROGER BOYD** devised a model of coordinated punishment in human societies that captures a phenomenon missing from other behavior models and experiments: The total social cost of punishing a slacker declines as the number of punishers increases.

A future quantum computer running Shor's 1994 factoring algorithm could break many of today's public-key cryptosystems, including those used for secure online transactions. Professor **Cris Moore** and collaborators showed, however, that the 1978 McEliece cryptosystem is immune to attack by all Shor-like algorithms, providing strong evidence that the McEliece system, which is implementable in today's computers, is destined to remain secure even if quantum computers can be built.

Distinguished Professor **GEOFFREY WEST's** and External Professor **LUIS BETTENCOURT's** search for the hidden laws underlying the growth and dynamics of cities received widespread press coverage in 2010. Articles appeared in *Nature*, *The New York Times Magazine*, *The Washington Post*, *New Scientist*, *Science News*, and on hundreds of blogs. Several radio and TV interviews with the researchers also aired.

A diverse group of experts met at SFI in April 2010 to study ecophylogeny, an emerging tool for ecological network research that combines ecology with evolutionary history to find relationships between ecological organization and relatedness among its species. Professor **Jennifer Dunne**, who co-organized the working group with External Professor **Jessica Green**, said ecophylogeny can provide a new framework to understand impacts of invasions, species loss, and habitat loss, which can better inform conservation.

A research team including External Professor **Harold Morowitz** and Professor **D. Eric Smith** modeled how molecular structures involving transition metal elements and ligands might have catalyzed the synthesis of basic biochemicals that acted as building blocks for more complex molecules, leading ultimately to life on Earth. Their work was part of a Frontiers in Integrative Biological Research (FIBR) grant from the National Science Foundation.

Determining what is genuine and what is not has long been a problem for art curators. It is estimated that 20 percent of the worldwide art market is fake. External Professor **Dan Rockmore** has developed a statistical technique that helps spot art forgeries.

SFI and Princeton University Press published the first two volumes in their collaborative series "Primers in Complex Systems," intended for non-specialists at the advanced undergraduate level or above. *Ant Encounters: Interaction Networks and Colony Behavior*, by Science Board member **Deborah Gordon**, examines ant behavior from the complex systems perspective. *Diversity and Complexity*, by External Professor **Scott Page**, shows how diversity makes fundamental contributions to system performance in complex adaptive systems.

SFI's first three Miller Scholars came to the Cowan Campus in 2010: renowned philosopher of science, consciousness, and evolutionary theory Daniel Dennett; physicist Seth Lloyd of MIT, whose research centers on the interplay of information with complex systems, especially quantum systems; and actor-playwright-director Sam Shepard. Former SFI Board Chair Bill Miller underwrites the Miller Scholars program to bring to SFI high-profile intellectuals to catalyze cross-disciplinary interactions.

A very small number of biased, complacent, or incompetent referees can significantly undermine the ability of the scholarly peer-review system to select the best scientific papers, according to modeling by External Professor **Stefan Thurner** and collaborator **Rudolph Hanel**.

Recent advances in biology, linguistics, and computer modeling, along with new archaeological finds, prompted SFI to host a September 2010 meeting that took a fresh, transdisciplinary look at the peopling of the Americas. Participants included geneticists, physical anthropologists, linguists, a mythology expert, and archaeologists.

SFI Professor SAM BOWLES' January 2011 multidisciplinary workshop on the coevolution of human behaviors and social institutions examined sea changes in social behaviors, such as the emergence of property rights following the onset of agriculture, and how changes in individuals' behaviors influence the behaviors of social institutions and vice versa.

SFI and the Santa Fe Symphony Orchestra explored the intersection of science and music in "Voyages of Discovery: The Planets." The October 2010 concert interspersed the works of Claude Debussy and Gustav Holst with projection images of the solar system assembled by Dr. Jose Francisco Salgado of Chicago's Adler Planetarium. Salgado and Omidyar Fellow **Simon DeDeo** provided accompanying commentary.

President Barack Obama in September 2010 announced his selection of External Professor **CARLOS CASTILLO-CHAVEZ** to the President's Committee on the National Medal of Science. Meanwhile, External Professor **DAN SCHRAG** and sabbatical visitor **CHRISTINE CASSEL** are members of the President's Council of Advisors on Science and Technology.

Professor J. Doyne Farmer's project—with collaborators and External Professors John Geanakoplos and Robert Axtell—to develop agent-based models of the economy was covered in *The Wall Street Journal*, *The New York Times*, *The Economist*, *Newsweek*, *Harvard Business Review*, and on CNBC.