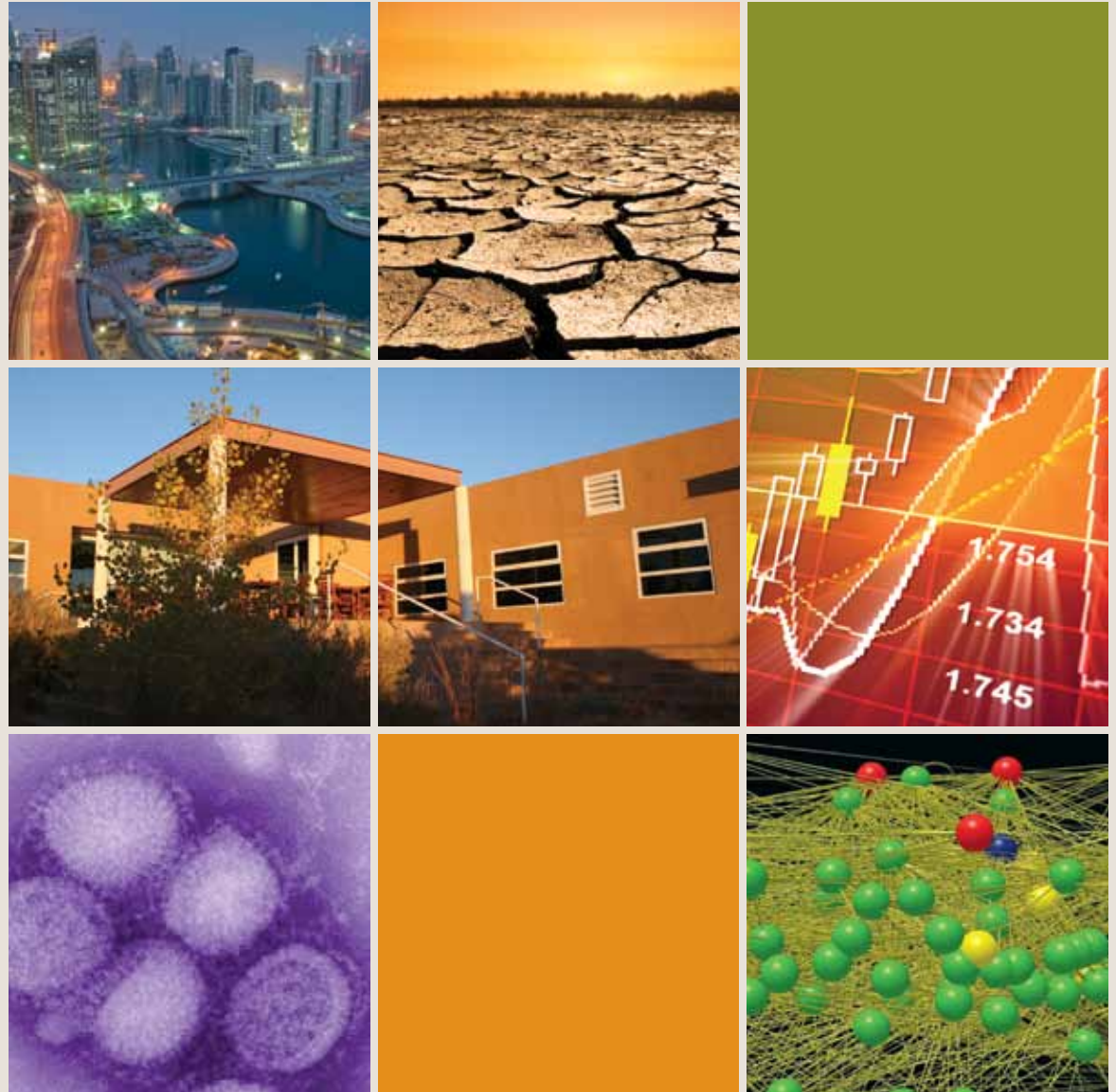




SANTA FE INSTITUTE



Science illuminating our complex world

2010 ANNUAL REPORT





>> insight

A UNIQUE RESEARCH COMMUNITY. A NEW KIND OF SCIENCE.

To unravel the complex systems most critical to our future – economies, ecosystems, world conflict, disease, human progress, and global climate, for example – a new kind of science is required, one that merges the riches of many disciplines, from physics and biology to the social sciences and the humanities.

For 27 years the Santa Fe Institute, the world locus of complex systems science, has devoted itself to creating a unique research community. In seeking the theoretical foundations and patterns underlying our world's toughest problems, SFI's scientists maintain the highest degree of scientific rigor, collaborate across disciplines, create and explore new scientific frontiers, spread the ideas and methods of complexity science to other institutions, prepare the next generation of complexity scholars, and encourage the practical application of SFI's results.

Founded in 1984, SFI is a private, independent, nonprofit research institution located in Santa Fe, New Mexico. Its scientific and educational missions are supported by philanthropic individuals and foundations, forward-thinking partner companies, and government science agencies.



SFI Leadership

Jerry Sabloff,
President

Nancy Deutsch,
Vice President for Development

Doug Erwin,
Chair of the Faculty, 2011-2013

David Krakauer,
Chair of the Faculty, 2009-2011

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WELCOME TO THE SANTA FE INSTITUTE

From SFI President Jerry Sabloff



“The best ideas often come from bringing groups of thinkers together from disciplines that normally have nothing to do with each other. The Santa Fe Institute is perhaps the best known example of this.”

– Duncan Green,
author of *From Poverty to Power*

Is SFI’s research relevant? Those who know the Santa Fe Institute know we concern ourselves with the underlying and often unseen structures, patterns, and connections in complex systems that, if we understand them well enough, might one day unlock the sorts of knowledge disciplinary science hasn’t yet revealed. This focus on the fundamental nature of things demands that we avoid the temptations of immediate, tangible outcomes.

Still, since I arrived at SFI in 2009, I have witnessed a growing appreciation for the Institute’s scientific research, not only among other scientists, but among policy makers and the public as well. For example:

- ▣ Our markets and risk work led by J. Doyne Farmer, John Geanakoplos, and colleagues is, in the wake of the global financial crisis, beginning to rattle the foundations of mainstream economics.
- ▣ Research led by Luis Bettencourt and Geoffrey West is providing fresh insights about urbanization, the rapid growth of cities, and the life cycles of companies.
- ▣ The work led by Jessica Flack and David Krakauer on the nature of conflict is suggesting ways to manage strife on many scales in a world in which environmental stresses and resource shortages soon may test our institutions, and our humanity.

SFI’s other explorations of cognition, evolution, the chemical origins of life, human behavior, ecological complexity, and

patterns of innovation are not only interesting problems in their own right, but unraveling them also requires a transdisciplinary approach in which the tools of physics and the natural sciences, the social sciences, and the humanities all contribute. Studying these issues in this way is rewarding, certainly, and potentially impactful. More important, it builds our theoretical understanding of complex systems generally.

So for me, the important question about SFI isn’t whether the Institute’s research is relevant. The better question is whether we are addressing key scientific questions in the right way. I believe the SFI model – a small, high-quality resident faculty core, an active and creative postdoctoral presence, a highly accomplished group of external faculty, plenty of transdisciplinary collaboration, complexity as a locus for thought, and an environment unfettered by the constraints of a university or government agency – is the right approach, for whatever the question. This way of thinking, and of doing science, and of addressing complex systems has explanatory power across the realm of human experience. Inevitably, relevance emerges from this process.

On behalf of SFI’s great faculty, fellows, and staff, I thank you for your interest in SFI. With your partnership and support we can begin to address some of our world’s most critical and complex problems.

Sincerely,

A handwritten signature in black ink that reads "Jerry A. Sabloff".

>> rigor

SFI Professors are in residence at SFI and are the core of the Institute's research and culture.

| | | | |
|---------------------|------------------|----------------|---------------------|
| Tanmoy Bhattacharya | J. Doyne Farmer | John H. Miller | Geoffrey West |
| Sam Bowles | Jessica Flack | Cris Moore | Jon Wilkins |
| George Cowan | Murray Gell-Mann | Jerry Sabloff | Elisabeth Jean Wood |
| Jennifer Dunne | David Krakauer | Paula Sabloff | Chris Wood |
| Doug Erwin | Fabrizio Lillo | D. Eric Smith | |

SFI PROFESSORS

Connecting conflict to hierarchy through collective social computation

An unanswered question in evolutionary theory is why life organizes itself hierarchically. From cells, to organisms, to societies, evolution generates structures nested in space and time. Organisms are made of molecules within cells within organ systems within bodies. Societies are individuals interacting in nested social networks, out of which persistent social structures emerge.

Although the possible explanations are many, few describe how new levels of organization arise in biological and social systems. SFI Professor **Jessica Flack** is proposing that evolution builds systems with multiple temporal and spatial scales to balance tradeoffs between evolvability (a system's ability to change in response to changing environments) and robustness (a system's ability to survive a wide range of threats).



Jessica Flack

Flack's hypothesis is that conflict is key to the emergence of hierarchy. New levels of organization arise as asymmetries resulting from competition among lower-level components become amplified. The emerging higher-level structure is essentially a coarse-grained representation – an average is a simple example – of the

lower-level conflict dynamics. As they interact, the components use the slowly changing coarse-grained statistics to make decisions, as these are more predictive of the future state of the system than the constantly in-flux events at the lower level. The in-flux events, on the other hand, allow the system to closely track environmental



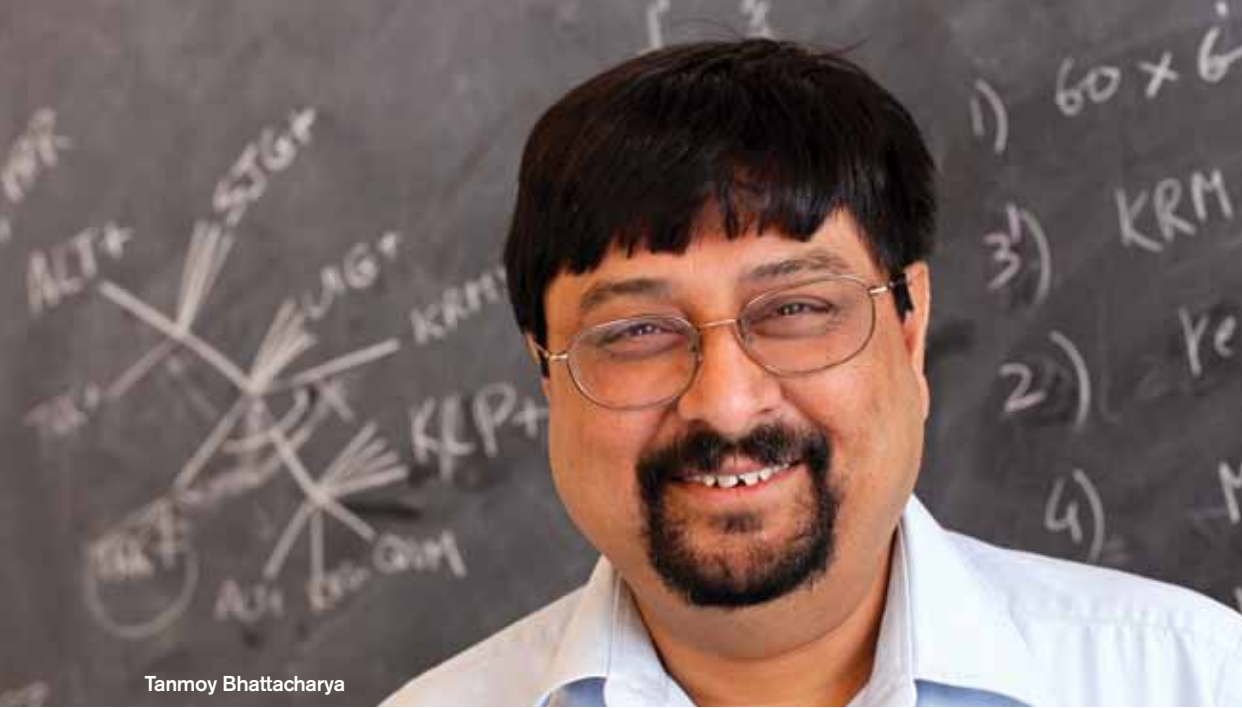
changes, preparing it to adapt. Thus, both fast and slow variables have important roles and benefits, she believes.

Flack argues that this process can give rise to structures as diverse as power distributions in human and animal societies, reefs, and brain regions associated with cognitive functions. Using conflict data underlying power structures in monkey societies, and data from brain studies showing how characteristic frequencies arise from the interactions of neurons, Flack and SFI Professor **David Krakauer** are seeking general computational principles that describe how slowly changing, coarse-grained variables arise from competitive dynamics and how components – whether they are people, monkeys, or cells – estimate the statistics of those variables.

SFI FOCUS AREAS

SFI researchers are giving four focus areas particular attention and effort. The areas and their faculty organizers are:

- ▣ **Risk, Markets, and Innovation** (J. Doyne Farmer)
- ▣ **The Multiple Scales of Conflict** (Jessica Flack)
- ▣ **Cities, Scaling, and Sustainability** (Luis Bettencourt & Geoffrey West)
- ▣ **Emergence in Decision Making and Cognitive Systems** (David Krakauer)



Tanmoy Bhattacharya

What viruses and languages have in common

As a physicist, SFI Professor **Tanmoy Bhattacharya** hunts for the elusive properties of particles in massive data sets. In a project led by SFI External Professor **Bette Korber**, he has studied HIV genetic sequences collected over the last two decades and traced the virus to its human origin in the early 1900s – and is using that knowledge to design a better vaccine.

On the surface these challenges seem impossibly dissimilar. For Bhattacharya, they are two manifestations of the same problem: understanding change in dynamical, or changing, systems.

Now he has turned his attention to the evolution of human languages. Linguists have devised systematic methods to understand language change, but those methods typically do not provide quantitative measures of confidence. In addition, unsophisticated use of statistical methods has sometimes in the past yielded incorrect results.

Bhattacharya believes languages go through combinations of regular and random change patterns that are similar to those physical systems and viruses go through. He considers language evolution a pursuit in need of a statistical overhaul. Using a vast database of Turkic languages, he and a team of SFI researchers have discovered law-like principles of change in language sounds through time and are developing a theory for shifts in meaning.

Bhattacharya is both an SFI Professor and a scientist in the Theoretical Division at Los Alamos National Laboratory.

Watching democratic attitudes form

SFI Professor **Paula Sabloff** explores the shifting concept of democracy across Mongolian society as its people – traditionally pastoral nomads with an arm’s-length philosophy about governance – have adjusted, since 1990, to their new democracy.

Her paper “Capitalist Democracy among Mongolian Herders: Discourse or Ideology?” (*Human Organization*, Spring 2010) shows how Mongolians use the discourse of democracy to express a more culturally nuanced political view.

In her 2011 book *Mapping Mongolia*, Sabloff challenges the convention of area-based studies of political regions. She is working on a textbook about Mongolian democracy and, with former SFI Omidyar Fellow **Tanya Elliott**, on a new application of connectionist theory to human groups.



Paula Sabloff

“[SFI will find a] common ground between the relatively simple world of natural science and the daily, messy world of human affairs.”

– George Cowan, founding SFI president



>>relevance

2010

“The patterns they’ve discovered [at SFI] have illuminated some of the most pressing issues of our time and, along the way, served as the basis for what’s now called the science of complexity.”

– *Wired* magazine

RESEARCH

In a paper appearing in *The Biological Bulletin*, a research team that includes SFI Science Board Chair Emeritus **Harold Morowitz** and Professor **D. Eric Smith** proposes a type of catalyst that could have jumpstarted metabolism and life itself, deep in hydrothermal ocean vents. According to their model, molecular structures involving transition metals and ligands could have catalyzed the synthesis of basic biochemicals that acted as building blocks for increasingly complex molecules.

A future quantum computer running Peter Shor’s 1994 factoring algorithm could break most public-key cryptosystems, including those used for secure online transactions today. SFI Professor **Cris Moore** and collaborators showed that the 1978 McEliece cryptosystem is immune to attack by all Shor-like algorithms, providing strong evidence that the McEliece system is implementable in today’s computers but destined to remain secure even if quantum computers are built and switched on.

SFI Professor **Sam Bowles** and External Professors **Herb Gintis** and **Robert Boyd** presented in 2010 a model of coordinated punishment in human societies that showed that the total cost of punishing a slacker declines as the

number of punishers increases. Groups with more punishers can sustain more cooperation and are more likely to survive crises and prevail in conflicts. Their work was published in *Science*.

SFI Omidyar Fellow **Simon DeDeo** and Professors **Jessica Flack** and **David Krakauer** developed new machine learning methods to study conflict. They applied the new method, which they call Inductive Game Theory, to a time series of fights gathered from detailed observations of a population of macaques. Their results demonstrate that conflict arises from complex interactions among groups of three or more, and the decision to fight is dependent on

memory for what happened in previous conflicts. Their work appeared in *PLOS Computational Biology*.

In an SFI working paper, SFI researchers **Bela Nagy**, **J. Doyne Farmer**, **Jessika Trancik**, and **John Paul Gonzales** put Moore’s Law to the test by analyzing historical datasets relating to performance improvements in information technology. They discovered that the data do not support the notion of exponential progress in information technology, but they do support a hypothesis of superexponential growth with decreasing doubling times. This raises questions about whether past improvement trends for information technology are sustainable.



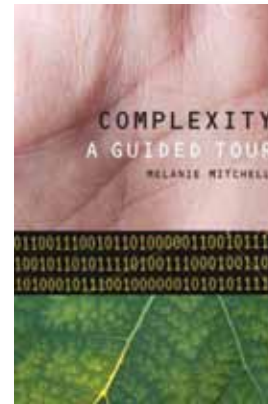
SFI IN THE NEWS

Distinguished Professor **Geoffrey West's** and External Professor **Luis Bettencourt's** search for the hidden laws underlying the dynamics and growth of cities received widespread media attention in 2010. Coverage appeared in *Nature*, *The New York Times* magazine, *Washington Post*, *New Scientist*, *Science News*, in hundreds of blogs, and on numerous radio and TV programs.

SFI Professor **J. Doyne Farmer's** project, with External Professors **John Geanakoplos** and **Rob Axtell**, to develop agent-based models of the U.S. economy was covered in *The Wall Street Journal*, *The New York Times*, *The Economist*, *Newsweek*, and the *Harvard Business Review*, among others.

The *Santa Fe New Mexican* featured SFI's **Project GUTS** (Growing Up Thinking Scientifically), an after-school and summer program that engages middle-school-aged scientists in questions about their world. The article was written by a high school student who participated in Project GUTS in 2007.

In the *Montreal Gazette*, SFI Professor **Sam Bowles** delved into the evolution of human cooperation, suggesting that at some point in human history, factions of cooperative humans – and the social institutions they created – might have put warrior factions at an evolutionary disadvantage.



BOOKS BY SFI AUTHORS

SFI 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.

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 SFI Science Board member **Deborah Gordon**, and *Diversity and Complexity*, by External Professor **Scott Page**.

SFI External Professor **Mark Newman's** book *Networks: An Introduction*, describes recent widespread interest in mathematical networks for understanding a variety of systems in computing, biology, sociology, and other areas.

2010 SCIENCE MEETINGS

Coevolution of Behaviors & Institutions (organized by Sam Bowles), January

Persistent Inequality (Sam Bowles & Monique Borgerhoff Mulder), January

Rethinking Aid to Support Economic Growth (Stuart Kauffman), February

Immune Response Consortium (Alan Perelson), March

The Ecophylogeny of Complex Species Interactions (Jessica Green & Jennifer Dunne), April

Archaeoastronomy

(Jerry Murdock & George Gumerman), May

Intelligent Data Analysis - Truly Understanding Complex Systems (Paul Cohen & David Krakauer), May

Reasoning, Perceptions, & Beliefs in Strategic Settings: Theory, Behavior, & Cognition (Willemien Kets), June

The Role of Entropy in Language & Communication (Mark Johnson & Katherine Demuth), June

Emergent Properties & Resilience of Interacting Networks (Raissa D'Souza), June

Metabolism as a Central Theme in the Emergence of Biological Order (Brian Enquist), July

Mechanisms of Neural Development

(Charles Stevens), August

Decentralized Control in Systems of Strategic Actors (David Wolpert, D. Eric Smith, & Robert Ecke), August

Viral Dynamics (Alan Perelson & Ruy Ribeiro), August

Cosmology & Society in the Ancient Amerindian World (Linda Cordell, George Gumerman & Murray Gell-Mann), September

Perception & Action (Nihat Ay), September

Peopling of the Americas

(Murray Gell-Mann, Henry Wright, & Ilia Peiros), September



>>reputation

EXTERNAL FACULTY

Outwitting HIV

HIV, the AIDS-causing virus, beats the human immune system by continually mutating itself. Thus, it is among the most diverse and elusive human viruses, and it has for decades confounded scientists trying to create a viable vaccine.

SFI External Professor **Bette Korber**, also a Laboratory Fellow at Los Alamos National Laboratory, is putting up a fight. She and her team of a dozen researchers have com-

plied a database of the genetic makeup of 300,000 different sequences of HIV. They are using a genetic algorithm to, as she explains, “mimic the evolutionary strategies the virus uses to evade the immune response.”

A better understanding of the virus’ adaptational patterns has enabled her to create a “mosaic” vaccine comprising artificial proteins that she says look and behave like HIV proteins. “*In vivo* tests showed the immune response was much better with the mosaic proteins than with natural ones,” she says – so much better, in fact,

that Phase I human trials for a mosaic vaccine are slated to begin in 2012.

Together with SFI Professor **Tanmoy Bhattacharya**, Bette also participated in a cross-disciplinary effort to combine evolutionary reconstruction with computational statistics to identify HIV mutations that possess the ability to be transmitted or to escape an immune response. That will allow researchers to further improve the vaccines, she says.



Bette Korber

“By recruiting exceptionally bright, open-minded people and placing them in a boundary-free environment which supports collaboration and innovation, SFI has made important contributions to science.”

– Harvard Interdisciplinary Study Group

Examining indoor ecosystems

SFI External Professor **Jessica Green** is developing new scientific approaches to understanding the complex ways microorganisms inside buildings interact with their environments, each other, and the humans who occupy those environments.

She was recently named a senior fellow by TED, and as part of her two-year fellowship she is raising awareness about this intersection of biology and architecture and how buildings may be designed to promote human health and environmental sustainability.

Green also is pursuing genomic- and theory-driven approaches to green design and sustainable urban development. “We can tackle urgent climate change and global health issues, in tandem, by advancing sustainable design practices,” she says.

She is an associate professor in the Center for Ecology and Evolutionary Biology at the University of Oregon, Eugene, and director of the University’s Biology and the Built Environment Center.



Jessica Green



Andreas Wagner

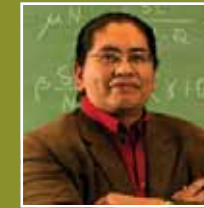
Evo-innovation ready for theory

Though Charles Darwin explained how natural selection preserves useful variations in biological phenotype, he was unable to describe the origins of these variations.

“There is something special about the architecture of life that makes it amenable to improvement through random change,” says SFI External Professor **Andreas Wagner**, head of the University of Zurich’s Institute of Evolutionary Biology and Environmental Studies. “It is more than just natural selection and random change.”

In his upcoming book *The Origins of Evolutionary Innovation*, Wagner suggests that the time is right for developing a unified theory of evolutionary innovation. While Darwin based his theory purely on observation of phenotype, our deeper knowledge today of organisms’ genotypes and the structure, function, and evolution of biological molecules, along with modern computational analysis tools, makes possible the organization, unification, and explanation of disparate evolutionary phenomena and innovation.

EXTERNAL FACULTY HONORS



President Obama announced in September 2010 his selection of SFI External Professor **Carlos Castillo-Chavez**, a professor at Arizona State University, to the President’s Committee on the National Medal of Science.

SFI External Professor **Nina Fedoroff**, a Professor at Penn State University and former science and technology adviser to two U.S. Secretaries of State and the U.S. Agency for International Development, was named president of the American Association for the Advancement of Science for 2011.

SFI External Professor **Simon Levin**, Moffett Professor of Biology at Princeton University, received the Eminent Ecologist Award for 2010 from the Ecological Society of America, ESA’s top award.

SFI External Professor **David Sherrington** (Oxford) was awarded the 2010 Blaise Pascal Medal in Physics by the European Academy of Sciences.

A paper in *Ecology Letters* co-authored by SFI Omidyar Fellow **James O’Dwyer** and External Professor **Jessica Green** was selected as the 2010 Outstanding Theory Paper by the Ecological Society of America’s Theoretical Ecology Section. The research provides a new mathematical model of species birth, death, and dispersal that draws from quantum field theory in physics.

SFI EXTERNAL PROFESSORS

SFI External Professors are affiliated with more than 70 research institutions in 20 countries.

David Ackley *

University of New Mexico

W. Brian Arthur

Palo Alto Research Center

Robert Axtell *

George Mason University

Nihat Ay

Max Planck Institute for Mathematics in the Sciences

Sander (F.A.) Bais

University of Amsterdam

Aviv Bergman

Albert Einstein College of Medicine

Carl Bergstrom

University of Washington

Luis Bettencourt

Los Alamos National Laboratory

Lawrence Blume

Cornell University

Robert Boyd

University of California, Los Angeles

Elizabeth Bradley

University of Colorado

Jim Brown

University of New Mexico

Timothy G. Buchman

Emory University School of Medicine

David Campbell

Boston University

Carlos Castillo-Chavez

Arizona State University

Morten Christiansen

Cornell University

Linda Cordell

School for Advanced Research

James P. Crutchfield

University of California, Davis

Lisa Curran

Stanford University

Raissa D'Souza

University of California, Davis

Vincent Danos

Université Paris-Diderot

Rob de Boer

Utrecht University

Andrew Dobson

Princeton University

Santiago F. Elena

Instituto de Biología Molecular y Celular de Plantas

Brian Enquist

University of Arizona

Joshua M. Epstein

Johns Hopkins School of Medicine

Nina Fedoroff

Penn State University

Marcus W. Feldman

Stanford University

Duncan Foley

New School for Social Research

Walter Fontana

Harvard Medical School

Stephanie Forrest

University of New Mexico

Steven Frank

University of California, Irvine

John Geanakoplos

Yale University

Herbert Gintis

Central European University
University of Massachusetts
University of Siena

Jessica Green

University of Oregon

George Gumerman

School for Advanced Research

Peter Hammerstein

Humboldt University

Bailin Hao

Fudan University

John Harte

University of California, Berkeley

James Hartle

University of California, Santa Barbara

Dirk Helbing

Swiss Federal Institute of Technology

John H. Holland

University of Michigan, Ann Arbor

Alfred Hübler

University of Illinois, Urbana

Ray Jackendoff

Tufts University

Matthew Jackson

Stanford University

Sanjay Jain

University of Delhi

Erica Jen

University of New Mexico

Jürgen Jost

Max Planck Institute for Mathematics in the Sciences

Stuart Kauffman

University of Vermont College of Medicine
Tampere University of Technology

Tim Kohler

Washington State University

Bette Korber

Los Alamos National Laboratory

Supriya Krishnamurthy

Swedish Institute of Computer Science

J. Stephen Lansing

University of Arizona

Simon Levin

Princeton University

Seth Lloyd

Massachusetts Institute of Technology

Jonathan Machta

University of Massachusetts

Pablo Marquet

Pontificia Universidad Católica de Chile

Lord Robert M. May

Oxford University

Stephan Mertens

Otto-von-Guericke Universität Magdeburg

Lauren Ancel Meyers

University of Texas at Austin

Melanie Mitchell

Portland State University

Michel Morvan

Ecole Normale Supérieure de Lyon

Mark Newman

University of Michigan, Ann Arbor

Kazuo Nishimura

Kyoto University

Maya Paczuski *

University of Calgary

Scott Page

University of Michigan, Ann Arbor

Mark Pagel

Reading University

Mercedes Pascual

University of Michigan, Ann Arbor

John Pepper

University of Arizona

Alan Perelson

Los Alamos National Laboratory

Juan Perez-Mercader

Centro de Astrobiología

Walter (Woody) Powell

Stanford University

Steen Rasmussen

University of Southern Denmark

Sidney Redner

Boston University

Dan Rockmore

Dartmouth College

John Rundle

University of California, Davis

Van Savage

University of California, Los Angeles

Hans Joachim (John) Schellnhuber

Potsdam Institute for Climate Impact Research

Daniel Schrag

Harvard University

Peter Schuster

University of Vienna

Rajiv Sethi

Barnard College, Columbia University

Cosma Shalizi

Carnegie Mellon University

David Sherrington

University of Oxford

Martin Shubik

Yale University

Ricard Solé

Universitat Pompeu Fabra

Peter Stadler

University of Leipzig

Charles Stevens

The Salk Institute

Steven Strogatz *

Cornell University

Alan Swedlund

University of Massachusetts, Amherst

Stefan Thurner

Medical University of Vienna

Joseph Traub

Columbia University

Constantino Tsallis

Brazilian Center for Physics Research
National Institute of Science and Technology

Sander van der Leeuw

Arizona State University

Andreas Wagner

University of Zurich

Duncan Watts *

Yahoo! Research

Colleen Webb *

Colorado State University

Ken Weiss

Penn State University

Douglas R. White

University of California, Irvine

William (Woody) Woodruff

Los Alamos National Laboratory

Henry T. Wright

University of Michigan, Ann Arbor, Museum of Anthropology

Peyton Young *

Nuffield College, University of Oxford

Wojciech Zurek

Los Alamos National Laboratory

*Rotated off 6/30/10

>> leadership

POSTDOCTORAL FELLOWS

THE OMI DYAR FELLOWSHIP

The Omidyar Fellowship plays a central role in SFI's creative, open intellectual environment. This highly selective postdoctoral fellowship brings to SFI fresh ideas from many fields, prepares fellows to be leaders in transdisciplinary science, contributes to SFI's research agenda, and spreads SFI's methodologies to scientific institutions around the world.

Omidyar Fellows spend up to three years in residence at SFI, during which they pursue research questions of their own design.

The Omidyar Fellowship is supported in part through an endowment established by eBay founder Pierre and Pam Omidyar, and by individual gifts – which are matched dollar for dollar by the Omidyars when they are contributed through SFI's Omidyar Challenge campaign.

2010 OMI DYAR FELLOWS

| | | |
|-------------------|------------------|-------------------|
| Rogier Braakman | Nathan Eagle * | James O'Dwyer |
| Caroline Buckee * | Tanya Elliott * | Scott Ortman |
| Aaron Clauset * | Laura Fortunato | Jessika Trancik * |
| Nathan Collins | Anne Kandler | Jeremy Van Cleve |
| Simon DeDeo | Willemien Kets * | |

2010 POSTDOCTORAL FELLOWS

SFI postdoctoral fellows are in residence from one to three years and collaborate with SFI faculty on research projects.

| | | |
|----------------|-----------------|--------------|
| Fabio Caccioli | Marcus Hamilton | Bence Toth * |
| Bryan Daniels | Bela Nagy * | Hyejin Youn |

* Completed fellowship in 2010

“In many respects the Santa Fe Institute is the ideal type of environment which facilitates creative thinking.”

– Rogers Hollingsworth, science historian, sociologist, and author

Fragile native tongues: The mathematics of a language's demise

To Omidyar Fellow **Anne Kandler**, the loss of a language is the dying breath of a culture. Combining her backgrounds in applied mathematics and cultural evolution, she has created a computational model of language shift, which she is testing on the Gaelic language of Scotland. She hopes to characterize the principles underlying the dynamics of how language use declines in a population, and identify the most crucial social policies governments might adopt to save them.

Using a wealth of U.K. census data going back 120 years, Kandler is examining historical trends in Gaelic speaking and identifying speaker-ratio inflection points below which Gaelic is not likely to recover without intervention. She also is refining her model, which, she admits, is now fairly crude, and waiting patiently for a 2011 census that will indicate whether government efforts have achieved some success, or whether Gaelic speaking continues to diminish in Scotland.



Anne Kandler

MILLER SCHOLARS

Challenging the status quo

Underwritten by SFI Board Chair Emeritus Bill Miller, the **Miller Scholars program** finds and brings to SFI high-profile intellectuals to challenge orthodox thinking and catalyze cross-disciplinary interactions. Three internationally renowned scholars came to SFI in 2010 as the Institute's first Miller Scholars:

- Philosopher of science, consciousness, and evolutionary theory **Daniel Dennett** spent five months at SFI beginning in January 2010. His research focuses on philosophy as it relates to evolutionary biology and cognitive science. He has written about and advocated the notion of memetics as a philosophically useful tool. At Tufts University, Dennett is co-director of the Center for Cognitive Studies and the Austin B. Fletcher Professor of Philosophy.



Daniel Dennett

- Self-described “quantum mechanic” **Seth Lloyd**, a professor of mechanical engineering at MIT and an SFI external professor, came to the Institute in July 2010. His research centers on the interplay of information with complex systems, especially quantum systems. In his book *Programming the Universe* he contends that the universe itself is one big quantum computer producing what we see around us, and ourselves. He is principal investigator at the MIT Research Laboratory of Electronics and directs MIT's Center for Extreme Quantum Information Theory.



Seth Lloyd

- Actor-playwright-director **Sam Shepard** arrived at the Institute in December 2010. Shepard is author of numerous plays, short stories, essays, and memoirs. He received the Pulitzer Prize for Drama in 1979 for his play *Buried Child*. He has appeared in more than 40 films, most notably as pilot Chuck Yeager in *The Right Stuff*, which earned him an Academy Award nomination in 1983. Shepard has directed two films and several of his own plays.



Sam Shepard

“The Institute’s atmosphere is like a cross between the senior common room of a Cambridge college and one of the West Coast temples of geekdom, such as Google or Pixar.”

– Science writer John Whitfield in his book *Life, Energy, and the Unity of Nature*



BUSINESS NETWORK

Selecting innovations likeliest to succeed

“The math and science behind a portfolio of stocks is relatively well understood,” says **Scott Mathews**, technical fellow with The Boeing Company, a Business Network member since 1999. “Discovering the same for a portfolio of technology innovations, a complex emergent system, is our goal at SFI.”

For the past two years, Mathews has been working with Institute scientists and other Business Network members to find ways to better predict which candidate technologies and products will be most suc-



Scott Mathews

“Some conferences provide food for thought. That was a feast.”

– Participant in 2010 Business Network meeting on uncertainty, risk, and vulnerability

cessful. In seeking new approaches, he blends his systems engineering and investment financial engineering experience.

The decision-making process can be complicated when it comes to forecasting technology success, he explains. A single Boeing product can take years to develop and hundreds of millions of dollars to fund. Boeing’s engagement with SFI researchers and other Business Network members helps the company formulate a scientific basis for this complex decision-making.

In a pre-competitive collaboration, Boeing and other Business Network members are sharing algorithms and methods, leveraging their research efforts with SFI, and creating new evaluation techniques. He believes his SFI involvement will not only be good for Boeing, “it will contribute to our national advancement of technology overall,” he says.

SFI welcomes first exploratory member

In 2010 SFI’s Business Network welcomed its first exploratory member, **Cerelink Inc.** Cerelink President Rod Sanchez says membership provides him with a “diverse set of insights and interaction with some of the world’s most creative companies.”

Cerelink, a Corrales, New Mexico-based cloud computing provider to the motion picture industry, recently supplied on-demand server capacity located in New Mexico to DreamWorks Animation for its rendering of two major animated pictures: *Shrek Forever After* and *How to Train Your Dragon*.

The exploratory membership category is designed for smaller companies, start-ups, and partnerships whose resources might not allow full Business Network membership. It gives such companies up to two years to participate in Business Network activities and to gauge the costs and benefits of full membership.

2010 SFI BUSINESS NETWORK MEMBERS

- Air Force Research Laboratory
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>> future

EDUCATION PROGRAMS

A short course long on demand

“Exploring Complexity in Science and Technology from a Santa Fe Institute Perspective” – unofficially known around SFI as “the short course” – introduces professionals from many backgrounds to the complex interactions that underlie social, biological, and computer behavior.

SFI External Professor **Melanie Mitchell** created the course based on her popular book *Complexity: A Guided Tour* (Oxford University Press, 2009). She leads the two-

and-a-half-day course, often collaboratively with fellow SFI scientists.

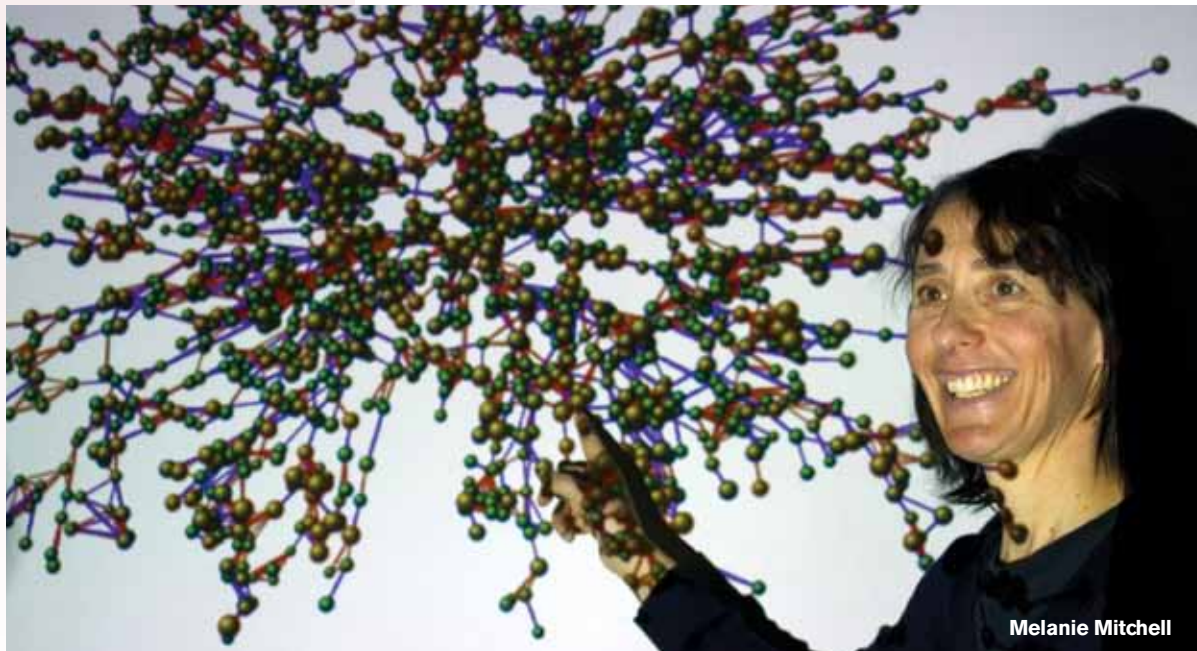
In two offerings of “Exploring Complexity” since its debut in 2010, more than 50 decision-makers in business, government, healthcare, education, media, and nonprofit organizations from many disciplines have attended.

During the course, participants explore the broad realm of complex systems science, including dynamics and chaos, networks, evolution, and agent-based modeling. They also

learn to use these tools to understand complexity in biological, economic, social, and technological systems.

“The interactions of such an eclectic group result in synergies of thought,” says Dave Snell, technology evangelist for RGA Reinsurance Company, who attended the May 2010 short course in Portland, Oregon. “When professionals from vastly different disciplines come together and reach an ‘aha’ moment, it is a magical experience.”

SFI offers the course at least twice a year in various locations.



Melanie Mitchell



A NEW VIEW OF LIFE'S ORIGINS

The National Science Foundation in 2010 funded – through its Frontiers in Integrative Biological Research (FIBR) program – a multi-institution effort to develop a new permanent exhibition for the New Mexico Museum of Natural History & Science in Albuquerque. “Emergence: A New View of Life's Origins,” takes a fresh look at the chemical origins of life. It replaces the museum's current origins exhibit, now 25 years old. SFI Science Board Chair Emeritus **Harold Morowitz** and Professor **D. Eric Smith** lead the project.

Where students become complexity scholars

Since 1988, SFI's signature education program, the **Complex Systems Summer School**, has trained more than a thousand graduate students and postdocs in the fundamental concepts of complex systems science.

In turn, those new complexity scholars have taken SFI's ideas and methods to their home institutions. Many have since joined the growing worldwide community of senior academics doing complex systems research, according to **Ginger Richardson**, SFI's Vice President for Education.

In 2010, 65 scholars from some 50 institutions and 20 countries came to Santa Fe to participate in the CSSS, organized by SFI External Professor **Dan Rockmore**. Students collaboratively completed 13 projects covering research topics from gossip and blogging patterns to diffusion processes in complex networks.

The 2011 school is changing in significant ways. Each course module, organized by a resident SFI scientist, is associated with a computation and data lab. Acknowledging the value of and demand for the school, SFI is for the first time charging tuition.

"We want to create a school that provides students with a synoptic perspective on core complex systems concepts with an emphasis on synthesis, and leave them with a portfolio of tools for analyzing real-world problems," says SFI Professor **David Krakauer**, the school's 2011 director.



"[SFI] is the formal birthplace of the interdisciplinary study of complex systems, now known as complexity science."

– Washington Center for Complexity & Public Policy

Engaging tomorrow's women scientists

Expanding on a successful SFI-led after-school science program for middle school students, the National Science Foundation in 2010 sponsored a new three-year program designed to attract New Mexico girls to careers in science, technology, engineering, math, and information and communications technology – fields in which women are historically under-represented.

"Learning technical and computing skills will give young people the background needed to succeed in these fields," says **Irene Lee**, principal investigator for the new program, **GUTS y Girls**, which provides extramural curricula for some 300 middle school girls.

Once-a-month Saturday workshops in Santa Fe offer girls the opportunity to meet women scientists and professionals, participate in hands-on projects, and learn about career options. Two-week summer workshops are being held in Santa Fe, Albuquerque, and Las Cruces.

The program is an outgrowth of the four-year-old, SFI-led Project GUTS (Growing Up Thinking Scientifically), an after-school program designed to encourage young people to ask questions about issues that affect their communities, investigate them through scientific inquiry, and devise potential solutions by modeling and analyzing them as complex systems.

Because girls tend to succeed when they see others like them succeeding, GUTS y Girls enlists women scientists as mentors and keeps girls and their mentors connected through a private social networking site.

If successful, the program could become a model for a national effort.

GUTS y Girls is a collaboration among SFI, MIT, the University of New Mexico, New Mexico Tech, New Mexico State University, the Santa Fe Complex, the Girl Scouts of New Mexico Trails, the Supercomputing Challenge, and New Mexico schools.



GOVERNANCE

More people thinking in an ‘SFI way’

Some things need an overhaul...the practice of economics, for example. That’s why **Jim Rutt**, Chair of SFI’s Board of Trustees, is immersing himself in the 600-page report from the National Commission on the Causes of the Financial and Economic Crisis. He wants to be able to explain, from his own complexity point



Jim Rutt

of view, the recent financial meltdown to people “so they will be outraged and ready for serious, radical change,” he says.

Other things don’t need such radical revision. The Institute, for example, has evolved over the nine years Jim has been involved, and he believes a gradually improving SFI has the power to change the world.

He sees a growing number of people and institutions thinking in an “SFI way.” He believes this is partly due to what he calls SFI’s “most powerful propaganda platform” – the Complex Systems Summer School. Well over a thousand students have participated since its debut in 1988, he explains. “Each brings the SFI mode of thinking back to his or her home institution.” Similarly, he credits SFI’s Business Network for bringing an SFI thought process to major companies.

“Most of the world’s major problems will be difficult to solve without complexity science. We have serious scholars working on serious issues, and SFI has a better, more powerful way of looking at things,” he says.

>> vision

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Deborah M. Gordon

Ant colonies as emerging networks

SFI Science Board member **Deborah M. Gordon's** preferred method for studying complex systems is observing ant colonies. Just as cells in a developing embryo differentiate without central control, no central authority governs the actions of individual ants. Yet an organized system emerges in the aggregate.

Her 2010 book, *Ant Encounters: Interaction Networks and Colony Behavior*, explains how the rate and pattern of interactions among individual ants create a dynamic network that coordinates the entire colony's functions. The book is the first in the series "Primers in Complex Systems," a collaboration between SFI and Princeton University Press.

Gordon is a professor of biological sciences at Stanford University.



“The Santa Fe Institute in New Mexico [is] the center of the intellectual universe for any researcher interested in complex interacting systems, whether in physics, biology, geophysics, social science, or anything else.”

– Philip Ball,
former editor of *Nature*

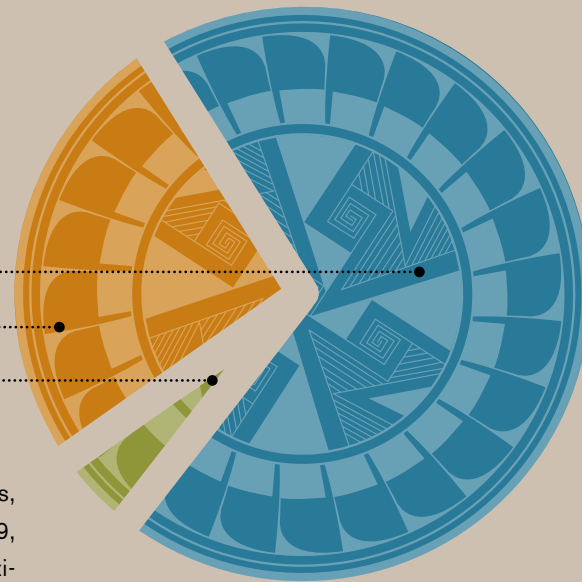


FINANCIALS

TOTAL EXPENSES

| | |
|-----------------------------|---------------------|
| Science Programs | 70% |
| Facilities & Administration | 27% |
| Development | 3% |
| Total | \$10,178,454 |

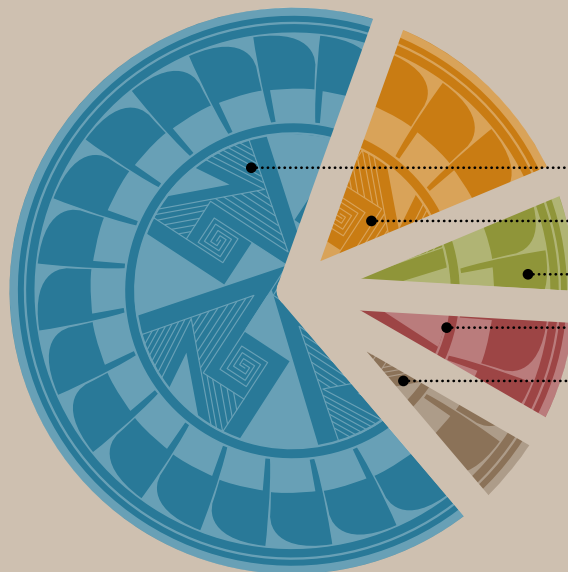
In response to continued economic uncertainties, SFI continued cost reductions initiated in 2009, resulting in 2010 total expenses that were approximately \$400,000 less than in 2009.

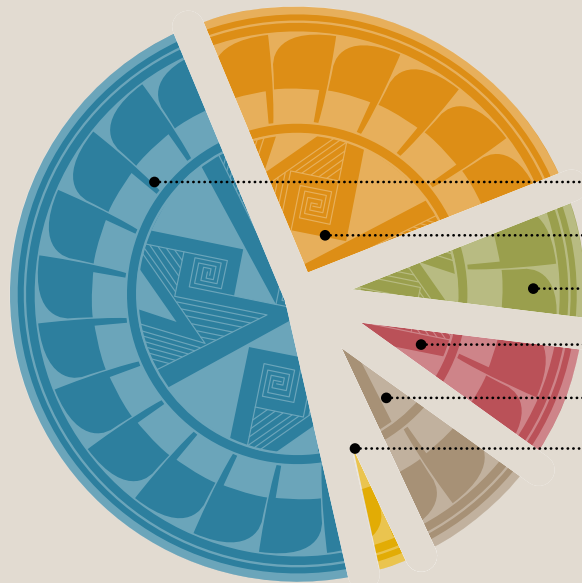


TOTAL SCIENCE PROGRAM EXPENSES

| | |
|----------------------------|--------------------|
| Research | 69% |
| Education | 16% |
| Business Network | 6% |
| Visits / Visitors | 6% |
| Workshops / Working Groups | 3% |
| Total | \$7,126,273 |

As in previous years, two-thirds of SFI's science program expenses were devoted to research, followed by education at 15-20 percent.





TOTAL REVENUES

| | |
|-----------------------------------|---------------------|
| Individual and Family Foundations | 41% |
| Government | 30% |
| Business Network | 10% |
| Philanthropic Foundations | 9% |
| Investment Income | 9% |
| Other | 1% |
| Total | \$11,379,528 |

In 2010 the distribution of revenue among contribution sources (individual and family foundations) and grants (government and philanthropic foundations) returned to more "normal" levels, after a sharp decrease in contributions in 2008 due to the economic crisis. Grant revenue remained relatively stable over the period of the crisis at approximately \$4.3-\$4.5 million. Revenues in this report include contributions designated for future expenditures and for endowment, but exclude pledges scheduled for future payment.

"My main response to people asking 'How was SFI?' has been 'Believe the hype!' The Institute is honestly one of the most inspiring places I have been to and I feel lucky to have had the opportunity to spend time there."

– Ben Ramalingam, author and visiting fellow, Institute of Development Studies, U.K.





>> commitment

“Santa Fe and complexity theory have become almost synonymous.” – Science writer John Whitfield

DONORS

Influencing a science revolution

Collaboration has been **Graham Spencer’s** stock in trade, from creating Excite in 1993 with five friends from Stanford, to launching JotSpot with Excite co-founder Joe Kraus. He appreciates the spirit of trans-disciplinary, collaborative research characteristic of SFI.



Peter Olivetti Photography

Graham Spencer

“I feel connected to the kind of science they do at SFI,” Spencer says. “They’re studying fundamental questions in a way that nobody else is doing it. People discover things they might not have, if they hadn’t been exposed to that

collaboration. I think the kinds of questions SFI is trying to answer are really foundational.”

As an SFI Trustee, Spencer plays an important role in guiding the Institute and promoting its research in the business and technology community. He and his wife, Cristina, support SFI financially as well. They believe their contributions to SFI go far because of its influence of the way people across many disciplines approach problems – including in the physical sciences, social sciences, computer networks, and business.

The theoretical nature of SFI’s research, however, makes it difficult for many donors to clearly see the impact of their philanthropy, and that holds some people back from giving, he says. “In my mind, that’s what makes it more important,” Spencer says. “SFI’s work is underappreciated relative to its importance.”



Simon DeDeo at Voyages of Discovery

2010 events

During SFI’s 2010 Ulam Lecture series in September 2010, External Professor and Science Board member **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.

SFI and the Santa Fe Symphony Orchestra explored the interface between science and music in **“Voyages of**

Discovery: The Planets,” an October 31 concert that interspersed the works of Debussy and Holst with projection images of the solar system and commentary by Dr. Jose Francisco Salgado of Chicago’s Adler Planetarium and SFI Omidyar Fellow **Simon DeDeo**.

In December 2010, SFI’s **Chris Wood** gave Silicon Valley investors an overview of the Institute’s research, and its promise, as part of a Thiel Foundation event highlighting the work of eight selected scientific non-profits.

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Lou and Hank Schuyler

‘A place like SFI is sorely needed’

Lou and Hank Schuyler believe they could be the first couple to become dedicated SFI donors during a vacation. In 1994 the pair left New York City to spend several restful days in New Mexico. Both have backgrounds in science – she in information technology, he through branding and market research – so an announcement of an SFI community lecture one evening caught their attention. And they were hooked.

“This is a world of increasing specialization,” says Lou, “with scientists studying the most minute details.” Yet, both she and Hank appreciate how everything in the world is connected and interdependent. Hank says he has “always felt a place like SFI was sorely needed.”

Six years ago, the two retired and moved to Albuquerque. They regularly attend lectures at SFI, Lou says, “to keep in touch with what’s going on at the forefront of science.”

Hank is pleased to have seen SFI grow and develop, citing such additions as the Business Network and a greater number of fellows. At the same time, he says, “SFI has remained true to itself...a brilliant, shining example of where innovation takes place.”

> continued next page

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Michelle Gaugy

Achieving immortality through art, and science

Artists attempt to achieve a kind of permanence – even immortality – in delicate brush strokes on stretched canvas, or in wood, fresco, or marble. Art dealer **Michelle Gaugy**, owner of Gaugy Gallery in Santa Fe, is more pragmatic. She wants to leave her mark on the world through beauty and science. A self-described “science groupie,” she deeply appreciates the patterns in art and life.

SFI Distinguished Fellow **Murray Gell-Mann**, Gaugy’s good friend, once chided her, saying she cared nothing for pure science. “I don’t care anything for science by itself, or art for that matter, or anything else by itself,” she admits. “What I care about is how everything connects, one to the other, then how it connects to humanity as a whole. I believe nothing has significance in and of itself.”

Over the 13 years Gaugy has lived in Santa Fe, her involvement in SFI has grown along with her passion for complexity science. She believes that while scientists can change the world with their insights, benefactors can likewise change the world by supporting that research. “I want to help progress and good in the world,” she says. “That commitment is my small measure of immortality.”

Gaugy has made sure her support will outlive her by making the Institute a significant heir in her estate. “SFI is doing work that is influencing the future of the world in groundbreaking ways,” she says. “And it needs more supporters. It deserves more supporters. It doesn’t even occur to people to put SFI in their estate plans – but it should.”



BECAUSE OUR WORLD ISN'T SIMPLE

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