



# Update

January / February 2012



## State of the Institute: A Q&A with SFI President Jerry Sabloff

At the turn of the new year, SFI President Jerry Sabloff gave the *Update* his thoughts on SFI's status and future.

**Update:** How would you characterize 2011 for SFI?

**Jerry:** It was a very productive and exciting year given the tight financial constraints we've been under. So there is a lot to be positive about.

The caliber of the scientists who come here remains high. The lunchtime talks, the afternoon colloquia, the public lectures, the events and workshops and working groups have all been provocative. Even though there were fewer science meetings overall, the ones we've had have been very good. So coming here every morning

and meeting new people and seeing new ideas emerge is still highly energizing.

We have a new chair of the faculty, Doug Erwin, who hit the deck running. David Krakauer's was a hard act to follow; his inaugural three years in the new position of faculty chair set a high standard. Doug has started strong and is meeting that challenge, and hopefully even exceeding it.

Winning a major new grant from the John Templeton Foundation has been an important success (see announcement below), not only because of the size of the grant but also because of the nature of the science it supports and the educational programs it embodies, both of which will involve many of the people at

SFI – faculty and postdocs as well as a number of our external faculty and science board members. Its three core research projects are well aligned with the Institute's science. That's going to have a strong positive impact on us, both scientifically and financially, for the next three years.

We have experienced a lot of change to our faculty recently. On the one hand we lost some key faculty members, but on the other hand we've gained two new full-time resident faculty members, Cris Moore and Luis Bettencourt (see story on page 2), and I think our search for additional resident faculty members is off to a good start. We've had a successful year of recruiting for Omidyar Fellows; we brought

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### RESEARCH NEWS

## Templeton Foundation grant supports complexity science

SFI has been awarded a major new grant from the John Templeton Foundation to pursue fundamental understandings of the hidden regularities in complex biological and social systems.

The Templeton Foundation is a philanthropic organization that supports research on subjects ranging from complexity, evolution, and infinity to creativity, forgiveness, love, and free will. More about the Foundation is available at [www.templeton.org](http://www.templeton.org).

The primary goal of the three-year, \$5 million SFI project is to generate new concepts and quantitative methods of general scientific and social value. It recognizes the opportunity presented by recent advances in data collection and computational power.

According to the grant award, the project "initiates a groundbreaking research program on the nature ... of complexity with the potential for illuminating many hidden regularities in the biological and social worlds."

The project "has the promise of developing fundamentally new quantitative theories" and focuses on "areas where new research and analysis are likely to make a real difference." Specifically, it supports three research efforts:

- The evolution of complexity and intelligence on Earth, led by SFI External Professor David Krakauer (University of Wisconsin-Madison).
- The hidden laws that pervade complex phenomena, especially biological and social

phenomena, led by SFI Distinguished Professor Geoffrey West

- Universal patterns in the emergence of complex societies, led by SFI President Jerry Sabloff

"All projects seek to understand the interconnectedness [among] competition, cooperation, and increasingly efficient and robust means of acquiring and communicating information," reads the grant award. "All projects consider the crucial role of multiple temporal and spatial scales in complex systems, why hierarchical and modular structure is ubiquitous, how mechanisms have evolved to exploit rapid changes in their surroundings, and how adaptive systems

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### RESEARCH NEWS

## Flintstone economics: Unearthing the roots of human disparity

After many millennia of relative equality within hunter-gatherer societies, the emergence of agriculture 10,000 years ago seems to have planted seeds of economic disparity and political hierarchy that have been sprouting ever since.

In a February working group, economist and SFI Professor Sam Bowles aims to unearth the roots of disparity in human societies.

Previous research with meeting co-organizer Monique Borgerhoff Mulder (UC Davis) and a host of others examined 21 small-scale societies to investigate how inequality emerges and persists. Their models

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### RESEARCH NEWS

## NSF grant to support research in 'natural computation'

All living organisms collect information from their environments and use it to adapt. Omidyar Fellow Simon DeDeo likes to think of this as a form of "natural computation."

Simon, with collaborator and SFI External Professor David Krakauer (University of Wisconsin-Madison), has been awarded a \$339,000 Advancing Theory in Biology grant from the National Science Foundation to investigate biological processes using the tools of computer science.

> more on page 4



## SFI IN THE NEWS

Discounting extreme market events as improbable is a long-held tradition in economics, but ignoring large, rare events doesn't capture reality. Power laws might do a better job of describing the distribution of large events, says a November 5 *Science News* article that cites four SFI researchers: SFI Professor Doyne Farmer and SFI External Professors John Geanakoplos, Stefan Thurner, and Mark Newman.

The growth of the global population beyond 7 billion people means the pace of innovation must also continue to increase, said SFI Distinguished Professor Geoffrey West at the Compass Summit conference, as reported in *Scientific American* on October 31.

In a Chinese-language paper published November 1 in *Caixin* magazine, SFI Professor Paula Sabloff recounts Mongolia's long, and continu-

ing, transition to a government and culture based on democratic values.

Crowds of people move in highly predictable ways and are best navigated at the edges, rather than the inside of the pack, according to a November 1 *Wired* article that quotes SFI External Professor Dirk Helbing, who has modeled crowd phenomena.

In a November 4 Q&A in *Popular Science*, SFI External Professor and Science Board member Seth Lloyd talks about the inner workings and future capabilities of quantum computers.

In an article about concerns over the income gap, *Foreign Policy* on November 14 reports that "an analysis by economists Samuel Bowles and Herbert Gintis at the Santa Fe Institute [shows that] of children born to the poorest 10 percent of parents in the United States, more

than half remain in the bottom fifth of incomes as adults."

A November 17 *Huffington Post* article reports on a study co-authored by SFI Faculty Chair Doug Erwin concluding that a mass extinction 252 million years ago was of a shorter duration than earlier estimates and was likely triggered by volcanic activity that caused a massive shift in climate.

It's true that cities are magnets for crime, pollution, and disease; but they also are centers of innovation, economic growth, and efficiency, argues SFI Professor Luis Bettencourt and Distinguished Professor Geoffrey West in a special *Scientific American* issue on cities in September.

**Find these articles and more SFI news – and sign up to receive notifications via Twitter, Facebook, or RSS – at [www.santafe.edu](http://www.santafe.edu).**

## ACHIEVEMENTS



SFI External Professor Scott Page is teaching a free online course beginning this month on the use of models to understand complex social phenomena. "Model Thinking" is among a series of online courses offered by a consortium representing the University of Michigan, UC Berkeley, and Stanford.



President Obama selected The Mathematical and Theoretical Biology Institute at Arizona State University, a program led by SFI External Professor Carlos Castillo-Chavez, as one of nine individuals and eight organizations to receive the 2011 Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring. ■

## > Roots of human disparity continued from page 1

demonstrate that hunter-gatherer and low-tech farming societies remain egalitarian through generations, whereas herding and more advanced farming societies tend to stratify economically and politically.

The reasons, Sam says, largely have to do with the ease of wealth inheritance: No matter how deft a hunter or efficient a gatherer, useful genetic traits and social skills essential to survival as a forager aren't consistently passed on to offspring.

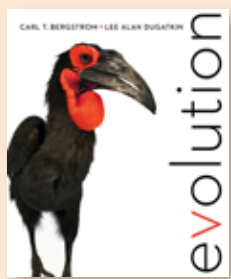
"The expression of a genetic predisposition that may make one a good hunter – strength or coordination, for example – is a very chancy thing," he says. "If you want to pass something useful on to your kids, make it be a cow."

The February working group will explore new questions, such as whether patterns of inheritance are similar along and across male and female lines of descent, the role of polygyny and inequality in mating success, and how inequality and authority may be related to the ecological setting in which a society resides.

Why should anyone care about these "Flintstone economics"? Sam asks.

"In tomorrow's knowledge-based economy the capacity for social networking and reasoning are essential forms of wealth surpassing material wealth in importance," he says. These hard-to-inherit forms of wealth – reminiscent of hunting and gathering skills – may push our economy in the direction of greater equality in the long run. ■

## SFI BOOK NEWS



*Evolution* (Norton, December 2011), a new undergraduate textbook by SFI External Professor Carl Bergstrom and Lee Alan Dugatkin, presents a contemporary view of the field, making major

themes and fundamental concepts accessible with extensive, in-depth, current research examples, an emphasis on phylogenetics and population thinking, and engaging art. ■

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The *SFI Update* is published bimonthly by the Institute to keep its community informed. Please send comments or questions to John German at [jdg@santafe.edu](mailto:jdg@santafe.edu).



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## RESEARCH NEWS

### Warming may prompt ill-prepared animals

What happens to animals as the climate warms?

In a paper published recently in *Proceedings of the Royal Society B*, two SFI researchers and their collaborators suggest ways some animals' developmental responses to a warmer climate may inhibit their abilities to thrive.

SFI External Professor Jim Brown (University of New Mexico), SFI Distinguished Professor Geoffrey West, and collaborators Wenyun Zuo, Melanie Moses (both of the University of New Mexico), and Chen Hou (Missouri University of Science and Technology) describe a general model for growth and development focusing on ectotherms: animals such as reptiles that regulate body temperature through external means (by basking in the sun, for example). Their model predicts that many

ectotherms may, in warmer environments, grow faster and mature at smaller sizes.

The model also suggests that some ectotherm species may hatch earlier in the year. This could be a problem, Jim says. If they hatch smaller, they may be more vulnerable to predators. In both cases, they may encounter an environment for which they are not well suited.

Another case: In some species such as crocodiles, sex is determined by temperature. If too many males or females are born, and they're too small, the population may have trouble reproducing.

In future work, the researchers will incorporate their model into answering one of biology's hardest questions: Why is there more biodiversity in the wet and warm tropics? ■



## BUSINESS NETWORK

### Meeting: Why is prediction so difficult?

"It is exceedingly difficult to make predictions, particularly about the future."

This quip has been attributed to Niels Bohr, Yogi Berra, Samuel Goldwyn, and Albert Einstein. Regardless of who coined it, says SFI VP Chris Wood, it nicely captures the focus of a recent SFI Business Network Topical Meeting, "Forecasting in the Face of Uncertainty and Risk," hosted by Morgan Stanley in New York.

The October meeting brought together scientists, economists, and representatives of the financial industry to explore, from a multidisciplinary perspective, the problem of forecasting.

Chris, who directs the Business Network, co-organized the event with Marty Liebowitz of Morgan Stanley, Michael Mauboussin of Legg Mason Capital Management (an SFI Trustee), and SFI External Professor John Rundle of UC Davis. It included presentations on the accomplishments and challenges of forecasting from experts in the physical sciences, economics, the financial services industry, even sports and politics.

Susan Avery, President of the Woods Hole Oceanographic Institution, discussed forecasting of atmospheric-oceanic events, including

the recent Hurricane Irene. U.S. Geological Survey Director Marcia McNutt reviewed the challenges of forecasting the nonlinear effects of climate change. Rundle discussed how the heavy-tailed statistics that describe earthquake frequency and magnitude can be applied to financial markets.

Ole Peters, a former SFI postdoctoral fellow now at Imperial College, described how an approach based on ensemble averaging that has dominated economic forecasting for nearly a century is based on an erroneous conclusion about an equation published in 1934. Careful attention to the appropriate time averages can better account for the risk inherent in financial markets, he said.

Financial experts Henry Kauffman, Rick Bookstaber, and Bill Miller participated in a concluding panel discussion moderated by co-organizer Liebowitz about financial forecasting and the importance of "outside-the-box" perspectives.

"There is great value in bringing together people who attempt to address the common problem of forecasting from different perspectives and based on very different kinds of data," says Chris. ■

## PEOPLE

### Two longtime SFI researchers join resident faculty



The Institute has named two longtime SFI-affiliated researchers to its full-time resident faculty.

Luis Bettencourt became an SFI professor on December 1, 2011. He had

been an SFI external professor since 2007 and a senior scientist in the Theory Division at Los Alamos National Laboratory. Luis carries out research in the structure and dynamics of complex systems, with an emphasis on dynamical problems in biology and society.

Currently Luis focuses on real time epidemiological estimation, information processing in complex systems, innovation in science and technology, and urban organization and dynamics. He has been an integral part of SFI's cities scaling project with SFI Distinguished Professor Geoffrey West, and is particularly well known for a 2007 paper in *Proceedings of the National Academy of Sciences* on scaling relationships in cities.



Cris Moore will become a full-time member of SFI's resident faculty in May. Cris was an SFI postdoctoral fellow from 1992 to 1998, an SFI research professor from 1999 to 2000, an SFI external professor from 2000 to 2007,

and a part-time resident professor since 2007. Currently he is a professor in the Computer Science Department at the University of New Mexico with a joint appointment in the Department of Physics and Astronomy.

His work focuses on quantum computation (especially post-quantum cryptography and the possibility of algorithms for graph isomorphism), phase transitions in NP-complete problems, and social networks (in particular, automated techniques for identifying important structural features of large networks). He is co-author of the recent and very well-received book, co-authored with SFI External Professor Stephan Mertens, *The Nature of Computation* (Oxford University Press, 2011).

Says Faculty Chair Doug Erwin: "Both Cris and Luis bring extraordinary quantitative skills coupled with interests in a broad range of problems in complex systems. Both have demonstrated their commitment to the SFI community, and we look forward to their leadership over the next five years." ■

**Video: SFI Distinguished Professor Geoffrey West** discusses the implications of metabolic rate scaling with species size. Source: MIT's Cambridge Nights interview.

**Audio: SFI's Chris Wood and the Santa Fe Symphony's Greg Heltman** discuss "Voyages of Discovery III: Bach On the Brain," a unique October concert in Santa Fe that explored the interface between music and brain science. Source: KSFR's Santa Fe Radio Café interview.

**Video: Molly Shaffer Van Houweling**, faculty director of the Berkeley Center for Law and Technology at UC Berkeley, explores how free access to digital media is blurring the lines between intellectual property

and individual expression, and what that means for copyright law. Source: SFI 2011 Community Lecture.

**Video: SFI External Professor W. Brian Arthur** explains how technology advances are signaling the emergence of a second digital economy that will change the complexion of culture and business forever. Source: Palo Alto Research Center presentation.

**Video: SFI External Professor and Yale economist John Geanakoplos** argues for banks to write down the balances on upside-down mortgages to spur an economic recovery. Source: MSNBC's Squawk Box.

**Audio: Mathematician and SFI External Professor Dan Rockmore** pays homage to the prime number 11

on the date 11/11/11. Source: Vermont Public Radio.

**Video: SFI Omidyar Fellow Jeremy Van Cleve** discusses how theories and principles from evolution might illuminate human social behaviors and institutions. Source: SFI video.

**Audio: SFI President Jerry Sabloff** describes what the Institute does, and why 2012 is a year for asking big questions at SFI. Source: KSFR's Santa Fe Radio Café.

**Audio: SFI Science Board member Lord Robert May** weighs in on 2011's top submissions to the BBC's regular feature on simple ideas to improve the world. Source: [www.bbc.co.uk](http://www.bbc.co.uk).

## > **Templeton grant** continued from page 1

have found a way of overcoming and exploiting the rapid turnaround and loss of their most elementary components."

"These projects fit the progression of SFI science very well," says SFI President Jerry Sabloff. "Although they are quite different in terms of the complex systems they examine – from genes and neurons to large human social systems – they all are concerned with the fundamental processes underlying complexity and the evolution of complexity. These are questions SFI has been asking since its founding in 1984.

"With the Templeton Foundation's generous support, we hope to make significant progress in understanding the principles that span and unify many complex systems," he adds.

### Coming soon: Complexity knowledge font

The grant also supports a significant education outreach project, says SFI VP Ginger

Richardson. As part of the grant, SFI will create an online resource called the Complexity Explorer. At the Explorer's core will be a wealth of learning materials associated with the sciences of complexity.

SFI's people have a long history of both developing the sciences of complexity and offering education programs in complexity, says SFI External Professor Melanie Mitchell, who is faculty coordinator for the Explorer project.

She says the online resource is intended for all levels of teachers and learners interested in complexity, including academics, graduate and undergraduate students, professionals, members of the public, and high school and middle school students.

A professor at a university might use the Explorer, for example, to interactively generate a recommended syllabus for a graduate level course in complexity, along with supporting



online exercises and simulations found in the Explorer's Virtual Lab.

A professional interested in applying complexity to business problems could search for and find relevant papers and paper summaries.

A student, who perhaps doesn't know where to start, will be able to find definitions pertinent

to the field and use multimedia demonstrations of complexity related principles and concepts, Melanie says.

"Wherever I go, people ask me where they can learn more about complex adaptive systems," she says. "This project, supported by the Templeton Foundation, will transform a longtime need into a reality." ■

## > **Q&A with Jerry Sabloff** continued from page 1

in two great young scholars, Charles Perreault and Evandro Ferrada, who I think will have a lasting impact on us.

David Krakauer gave a terrific three nights of standing-room-only Ulam Lectures in the fall, and our community lectures have been very well and enthusiastically attended.

We started the year under very tight fiscal constraints, just like the majority of nonprofits in this country. These are tight times given the state of the economy, the nature of philanthropy, and the trends in government and foundation funding. Despite those, I think we've done as well as we could have. That's a very positive result for the year, and I remain optimistic for the future.

**Update:** What are the Institute's primary challenges for 2012 and beyond?

**Jerry:** The top one, as it has been since 2008, is our financial picture. That we've been able to flourish under severe financial constraints so far is a remarkable testament to the faculty, postdocs, and staff, who have rallied terrifically. But those problems have not gone away, and until we see the economy begin to pick up – we hope sooner rather than later – we are going to have those constraints. We've been looking for new ways to be more efficient without major impacts to our programs. SFI's education program is one example; by changing the business plan for education, we are keeping up a high level of outreach at a minimal cost for the Institute. This was the challenge I gave Ginger Richardson just over a year ago, and she continues to find ways to improve the model.

What we need to focus on now is finding new sources of funding, primarily by expanding our donor base. Nancy Deutsch and I and the Board [of Trustees] are working hard on that, but we have a long way to go. Elisabeth Johnson also is doing a fantastic job of working with foundations and government agencies, trying to find additional support for our science. So even though the fiscal challenges are not going to go away, the good news is we are sort of battle hardened, and I think everyone in the building is aware of these challenges and doing everything they can to meet them.

The other major challenge obviously is finding the highest quality faculty and postdocs. That's always been a challenge the Institute has met, but we have to continue to find ways to better support our scientists, which is closely related to the financial picture as well.

*"We are in a time when some of the most difficult problems for humankind tend to relate to complex adaptive systems."*

**Update:** You mentioned SFI has lost some key people in the last six months. What do these losses, and openings, mean for the Institute?

**Jerry:** Eric Smith. Jon Wilkins. David Krakauer. Jessica Flack. These are real losses for us. But it is important to recognize that the way SFI is set up, turnover is the norm. That we are losing a number of key resident faculty members, and all at the same time, certainly is a challenge. It clearly would be better if departures were more staggered. But continually having our researchers move into academia while bringing in new minds with fresh ideas is one of the design features that distinguishes the Institute from a department at a major university. Here, with limited terms for our faculty and no tenure, that is how we keep this place exciting and fresh.

In our history, more than a quarter of century now, we've lost some really major people who have gone on to terrific jobs and gained recognition in broadening the reach and scope of complexity science: Stu Kauffman, Walter Fontana, Melanie Mitchell, Jim Crutchfield, Mark Newman, among many others – there is a much longer list of really exceptional people who have been here. David and Jessica were actively recruited by the University of Wisconsin-Madison, but they will continue to have an SFI affiliation and conduct SFI research. People who spend time here tend to go on to very attractive positions, and when they take SFI's approach and the sciences of complexity with them, that's good for the Institute.

So we just have to seize this opportunity by bringing in people with strong quantitative and interdisciplinary backgrounds who are committed to understanding the evolution of complexity at multiple scales and time frames. We need people with a great deal of energy and a strong intellectual curiosity, who are willing to challenge the accepted wisdom and ask tough new questions and look at new techniques to answer them – to go beyond traditional scientific and academic modes.

Cris Moore and Luis Bettencourt – our newest full-time resident faculty members – are great examples. Both are very strong in quantitative methods. Both have been working on important problems in a number of areas. Both have track records of collaborating with SFI faculty and postdocs and securing grants and so forth, and my expectation is that both will become even greater forces at SFI. Our new faculty search has just been launched, and I have no reason to believe we won't be successful in finding a few more really great matches.

**Update:** Why is a place like SFI important?

**Jerry:** It is SFI's role to ask big questions. Fundamentally, what are the characteristics of a complex system, and how and why does complexity emerge at various scale and time-frames? By examining these fundamental questions in many kinds of systems, from atoms and neurons to large social systems, we might begin to address some of the major issues in science and society.

And the need for an SFI approach is clearly more pressing than ever, as we are in a time when some of the most difficult problems for humankind tend to relate to complex adaptive systems. Last year we witnessed the Arab Spring, which looks a lot like a phase transition in a sociological setting. Financial markets continue to fluctuate wildly, sometimes shifting by 300 points in a single day. These complex systems are amenable to new analyses, as SFI scientists have shown. Those are just two of a vast number of examples that urge us to better understand the nature of complex systems generally. That's why we are here. ■

## RESEARCH NEWS

### What preceded life's rapid diversification?

A study published recently in *Science* offers a new perspective on the evolutionary precursors to the Cambrian explosion 541 million years ago.



The researchers, including SFI Faculty Chair Doug Erwin, matched genetic

sequences for more than 100 living animal species to the fossil record, concluding that complex animals originated roughly 800 million years ago, a more precise date than previous estimates.

They further concluded that the developmental toolkit required for producing basic structures and functions in complex animals was largely in place by the time the early ancestors of jellyfish and sea anemones emerged 700 million years ago.

They propose that for the millions of years until the Cambrian explosion, sponges and simple animals gradually altered their environments, while new species formed ecological relationships, enabling still more ecological engineering.

These environmental and ecological changes allowed animals to take advantage of the potential in the developmental toolkit that provided building blocks of animal diversity. Together, these processes created a positive feedback loop that led to the explosion of diversity in the Cambrian.

"By carefully integrating the fossil and molecular data, we were able to separate the timing of these events," says Doug. "This gives us a much better understanding of how the processes are linked." ■

## EDUCATION

# Dutch visit 'the first of many' like it

For a week in September, a group of 15 Dutch business and government executives visited SFI, participating in what may become a model for future SFI educational outreach interactions.

The Dutch were with the Comenius program associated with the University of Groningen. The workshop brought them into intimate contact with more than a dozen SFI faculty members and their research in the sciences of complexity.

SFI External Professor and workshop director Sander Bais says the diversity and accessibility of the program helped participants with backgrounds varying from art to medical practice to banking get acquainted with complexity science views on today's problems. "They

learned of connections that may inspire them in their management and governing capacities," he says.

Edwin Mac Gillavry, deputy director of the Bureau for Criminal Law Studies of the Dutch Public Prosecution Service, said the time at SFI "had a liberating effect. The beauty of in-depth research of complex issues in a multi-disciplinary setting is inspiring."

SFI VP for Education & Institutional Outreach Ginger Richardson says the unique event "allowed us to reach an audience of international professionals thinking at the cutting edge of their respective fields" and introduced a new, more intimate outreach format. It was the first of many of this nature to come, she says. ■

## DONOR PROFILE

# Gerry Ohrstrom: Clarifying the paths to innovation and social prosperity



Philanthropist Gerry Ohrstrom believes the Institute is making the world a better place by using tools and perspectives from the natural sciences to understand social systems. But, he admits, self-interest is part of his philanthropic motivation.

"You can't make the world a better place if you don't make yourself a better person," he says. "A good way to start is by meeting creative and accomplished people who challenge and inspire your thinking. There's no better place for that than SFI."

SFI's Business Network meetings and scientific symposia, he says, are opportunities for donors and friends of the Institute to grow

intellectually and connect with people who do the research.

An active follower of trends in science and social policy, Ohrstrom had been aware of SFI's research since the 1980s, but he became involved after a friend, SFI Trustee John Chisholm, formally introduced him in 2010.

He says he appreciates the way SFI brings together disciplines such as physics and biology to better understand the drivers of societal well-being. Ultimately, this greater understanding illuminates more specific concerns, such as poverty and disease, and clarifies the paths to innovation and prosperity, he says.

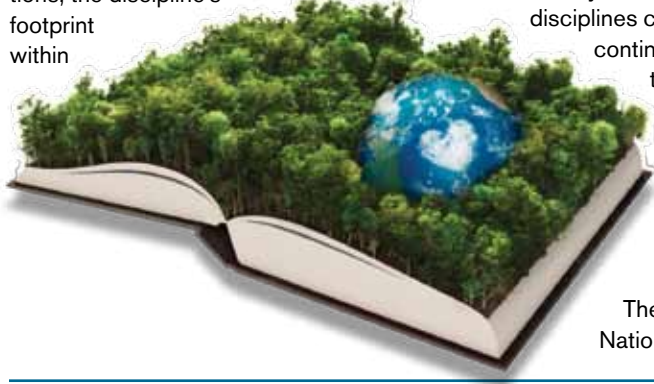
Ohrstrom is an investor in New York City with a background in private equity, investment banking, and manufacturing. ■

## RESEARCH NEWS

# Is sustainability a science?

Is there a science of sustainability, or does it remain a catchall for a motley collection of scientific studies, policy efforts, and causes?

In a study published in *PNAS*, SFI Professor Luis Bettencourt and Jasleen Kaur (Indiana University) assembled the history of sustainable development – some 20,000 academic papers by 37,000 authors, all published between 1974 and 2010 – and analyzed the evolution of authors, their geographic distributions, the discipline's footprint within



scientific disciplines, and other indicators.

"We find that around the year 2000 the work in this area had coalesced to the point where most contributors and clusters of contributors were connected into a single, global collaboration network, and the field was producing and drawing from unified sets of concepts and theories," says Luis.

They also find that sustainability science is widely distributed globally; that many disciplines contribute; and that the field continues to be fast-growing, with the number of authors doubling every 8.3 years.

"This evidence bodes well for the continued impact and longevity of sustainability science," Luis says.

Their work is supported by the National Science Foundation. ■

## RESEARCH NEWS

# Information technology progress not slow or steady, but superexponential

SFI researchers have studied the pace of technology improvements over the last century and found that, rather than improving at a (merely) exponential rate as some have theorized, information technology has improved superexponentially – which is to say, its progress accelerates.

Their work appeared in the October 2011 edition of *Technological Forecasting & Social Change*.

Former SFI postdoctoral fellow Bela Nagy, Professor Doyne Farmer, former Omidyar Fellow Jessika Trancik, and SFI student researcher John Paul Gonzales based their results on a comprehensive Performance Curve Database they created, which collects performance measures of technologies dating to the 19th century.

Using these curves they tracked information processing improvements in three areas: information storage per unit volume, communications bandwidth, and computation speed.

In every performance curve the team plotted, a single exponential could be definitively rejected in favor of a superexponential curve.

John Paul says this research suggests an accelerating rate of improvement in technology, noting that history has shown that when a technology reaches its limit, a new technology that serves the same purpose, but better, often comes along to replace it. Mechanical calculators, for example, were replaced by vacuum tube mainframes, and it is reasonable to assume that some new technology will take the place of the integrated circuits we now use to compute.

If these trends continue, he says, "in some ways things will continue to get better. In that sense it is a hopeful paper."

The Performance Curve Database, which tracks performance for many and widely disparate technologies, is open and available to the public at <http://pcdb.santafe.edu/>. ■

## INSIDE SFI

# Symphony combines Bach, brain science

On October 30 in Santa Fe, SFI and the Santa Fe Symphony collaborated to produce a unique event exploring the interface between music and brain science. "Voyages of Discovery III: Bach On the Brain," featured selected works of Johann Sebastian Bach interspersed with commentary by neuroscientist and SFI VP for Administration Chris Wood (seen here) and demonstrations of the brain's response to sound and music. It was the third SFI-SFS "science symphony" in as many years. Two special "Bach On the Brain" concerts for New Mexico 4th graders were performed on October 31.



### > *Natural computation* continued from page 1

The study applies classical computational theory to understand the unusual and counterintuitive ways evolved systems – as opposed to engineered systems – might compute.

"When you look at biological systems in the right way, you find this question of natural computation arise again and again in different forms – for things as small as a single cell to as large as a social group," says Simon, the principal investigator on the grant. "What happens when you open biology to what is now almost a hundred years of progress in computer science is only beginning to become apparent."

In addition to funding new research and collaboration in natural computation, including support for graduate and undergraduate

students (the latter through SFI's Research Experiences for Undergraduates program), the grant also brings natural computation to New Mexico middle school students participating in SFI's Project GUTS (Growing Up Thinking Scientifically) after-school science education program.

"While advances in 20th century mathematics often went hand-in-hand with the demands of physics, it seems likely that many of the most challenging problems for mathematics in the 21st century will come from biology," he says. "This grant lets us take some first steps in that direction."

Watch Simon describe natural computation in an SFI video at [www.santafe.edu/omidyar-fellowship](http://www.santafe.edu/omidyar-fellowship). ■

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