SANTA FE INSTITUTE

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UPDATE

Better ways to forecast technological change

The tricky business of forecasting technological change is usually done in one of three ways: by treating new technology as a featureless, exogenous shock (referring to "black box" type models); by describing technology in terms of experience or learning curves that improve cost performance; or by relying on the often wildly varying opinions of experts.

But these are all ways of describing in highly aggregated fashion what economists are seeing as outputs rather than what causes those changes. To really understand technological change, you need to examine its underlying drivers and the motivations of the people and firms making it happen, says economist Deborah Strumsky of UNC Charlotte.

Researchers invited to a working group at SFI this summer are studying technology, especially alternative energy technologies, as trophic networks akin to food webs that describe feeding interactions in ecosystems. The food web-like approach enables them to place a particular technology within its ecosystem and study how it evolves. Like food webs, these networks have hierarchical structures, but they are based on individual technologies' distances from the natural resource-based inputs needed to create them.

The interesting dynamic in this approach,

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EDUCATION NEWS

Code.org takes SFI's Project GUTS to nation's classrooms

SFI's Project GUTS (Growing Up Thinking Scientifically), an afterschool program for New Mexico middle school students, is gaining national reach this summer.

Code.org, a Seattle-based nonprofit whose mission is to establish computer programming in the curriculum of every U.S. school, has incorporated Project GUTS into its national initiative to bring computer science to middle school science classrooms.

Irene Lee, Director of SFI's Learning Lab and founder of Project GUTS, says her team of educators has customized existing Project GUTS afterschool modules for integration into science classes and started preparing teachers to use them.

"We'll be offering workshops that prepare teachers from large school districts to implement the modules we wrote," she says. "That's how the modules will get disseminated this summer and implemented next school year. Next summer Code.org wants to add more modules and prepare additional teachers in more large school districts."

Having worked with Lee in the past, Pat Yongpradit, Director of Education at Code.org, says he knew adopting Project GUTS would be a good fit and that SFI's program is a great model for teaching computer science to young people.

Project GUTS began in 2007 in a handful of Santa Fe-area schools. The program has gradually expanded to include some 21 schools across the state. Project GUTS received national attention last year when the Afterschool Alliance and the Noyce Foundation recognized the program with one of two national Afterschool STEM Impact Awards.

Lee says she believes every child should have the opportunity to create models and run simulations to test ideas and learn about systems, skills she believes should be universal – like problem solving and critical thinking.

"I'm very much a product of public schools, and I've seen that there are bright individuals everywhere," she says. "Kids deserve a chance, and whereas previous programs focused on finding the 'best and the brightest,' I think for many the early development of skills was a matter of exposure and privilege. There are kids all over the world who should have equal access and exposure to educational opportunities. That continually drives me."

To support Project GUTS, contact Lee at lee@santafe.edu. ■

IN THIS ISSUE

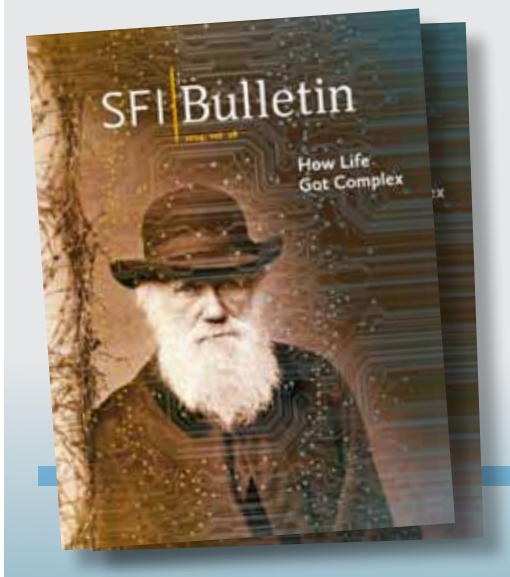
RESEARCH NEWS

Statistical mechanics after 25 years

Complex systems don't always follow the rules – often, they don't even follow the rules of ordinary statistics.

A quarter century ago, that revelation paved the way for a new approach to complex systems – from biology to high-energy particle physics – that takes into account the often strong correlations between systems' component parts.

> more on page 2



The new issue of SFI's interactive science magazine, the *SFI Bulletin*, is online. In our spring 2014 issue, "How Life Got Complex," SFI External Professors Jessica Flack and David Krakauer ask why, and how, many biological systems on Earth have evolved to be ever-more complex, even intelligent. Existing explanations don't get us there. As Krakauer writes so eloquently: "The theory of everything is a theory of everything except of those things that theorize." The issue is available at www.santafe.edu/bulletin.

A front-page *Wall Street Journal* article on June 30 profiles SFI Chair Emeritus Bill Miller, featuring his longtime relationship with SFI. Miller is quoted: "You don't come [to SFI] to get an answer to something. You come here to understand things in a different way."

On the Santa Fe Radio Café on June 18, SFI Professor Luis Bettencourt describes recent insights from SFI's cities and urbanization research and what they imply for human development.

Ensia magazine on June 16 asks five experts, including SFI Professor Luis Bettencourt, what they think the world's cities will be like in the year 2050.

In the *New York Times* and *New Scientist*, former SFI Omidyar Fellow Simon DeDeo describes a June 16 PNAS paper he co-authored with former SFI graduate fellow Sara Klingenstein and collaborator Tim Hitchcock. Their analysis reveals cultural shifts in 150 years of court transcripts from London's Old Bailey criminal court.

A June 12 article in the *San Francisco Public* Press notes that urban renewal can bring welcome change to failing neighborhoods, but planners must continue to evaluate those well-intentioned efforts and ask "what's next" to blunt some of the unintended consequences. The article quotes SFI Professor Luis Bettencourt.

In a June 9 *Huffington Post* interview that grew out of a chance encounter in SFI's courtyard, SFI Science Board member Nigel Goldenfeld discusses "the hegemony of the culture of Darwin" and today's theoretical frontiers in evolutionary biology.

In the *Santa Fe New Mexican* on June 9, SFI Research Experiences for Undergraduates student Emma Wolinsky describes how taking advantage of SFI education programs has helped guide her along a career path in complexity science.

A special May 23 issue of *Science* explores the origins of human inequality, drawing on research by SFI Professor Sam Bowles and his collaborators on wealth inheritance.

A May 22 article in *Aspen Peak* magazine describes how a conversation with SFI's Murray Gell-Mann at the 2009 Aspen Ideas Festival inspired oncologist David Agus to change the way he thinks about cancer.

SFI's Sam Bowles and Herbert Gintis were among the "young radical economists" at Harvard in the late 1960s whose skepticism about the mainstream paradigm has since gained credibility, according to a May 1 feature in *Adbusters* magazine.

In *PNAS* on April 29, Martin Scheffer suggests reforming scientific practice by reinforcing the associative side of thinking, citing SFI as a model institution.

In an April 29 column in *Green Money,* SFI Trustee Katherine Collins asks "What would nature do?" and explores how that question can inform decisions about investing.

Nearly 30 years ago Seth Lloyd, now an SFI Science Board member, sought to explain the apparent directionality of time as the increas-

Nonlinearities
From the editor

Three times during SFI's recent Science Board Symposium I witnessed an interesting phenomenon. As a speaker approached the dense portion of her or his talk, a Greek-laden slide appeared and the speaker, gesturing dismissively, would say, "And here's the math, blah, blah, BLAH." I don't mean each speaker uttered a bunch of words that sounded to me like "blah, blah, blah." What I mean is the speaker actually said "blah, blah, blah" as an abbreviation for all the math that fits on one slide. The meaning here, of course, is "rest assured I have done the math but I'm not going to bore you with it." Speaking for myself, much appreciated, three speakers. One "blah" is worth a thousand words.

This year's Symposium, themed "Theory in Practice," was an important reminder that this stuff matters well beyond our scientific cloisters. One talk was particularly entertaining. With the blockbuster movie *Godzilla* soon hitting U.S. big screens, SFI's Geoffrey West bookended his talk on biological and urban scaling with some back-of-the-napkin calculations of the physiological characteristics of the city-stomping behemoth (that is, given what is known, what does our theory tell us?). Here are the highlights: At 350 feet tall, Godzilla's metabolic rate is a megawatt; its aorta is the radius of a 727; it would live about 2,000 years; its gestation period is 15-20 years; it would have, on average, just 0.3 offspring; and, perhaps most reassuring, it would collapse under its own weight. In other words, Godzilla is biologically impossible. I don't know about you, but for me this is comforting news. You can watch all the talks under the "Videos" link at www.santafe.edu.

The middle of this issue features an introduction to our new SFI Omidyar Fellows for 2014. By all accounts the selection process this year was the most competitive to date. Some 300 applications were reviewed by our faculty. Thirteen candidates were invited to SFI to give talks. The six selected are an impressive bunch. I invite you to get to know them on pages 4 and 5. Also on page 5, we feature two outstanding new postdoctoral fellows, selected to work with SFI faculty on specific research programs. ■

– John German, jdg@santafe.edu

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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*.

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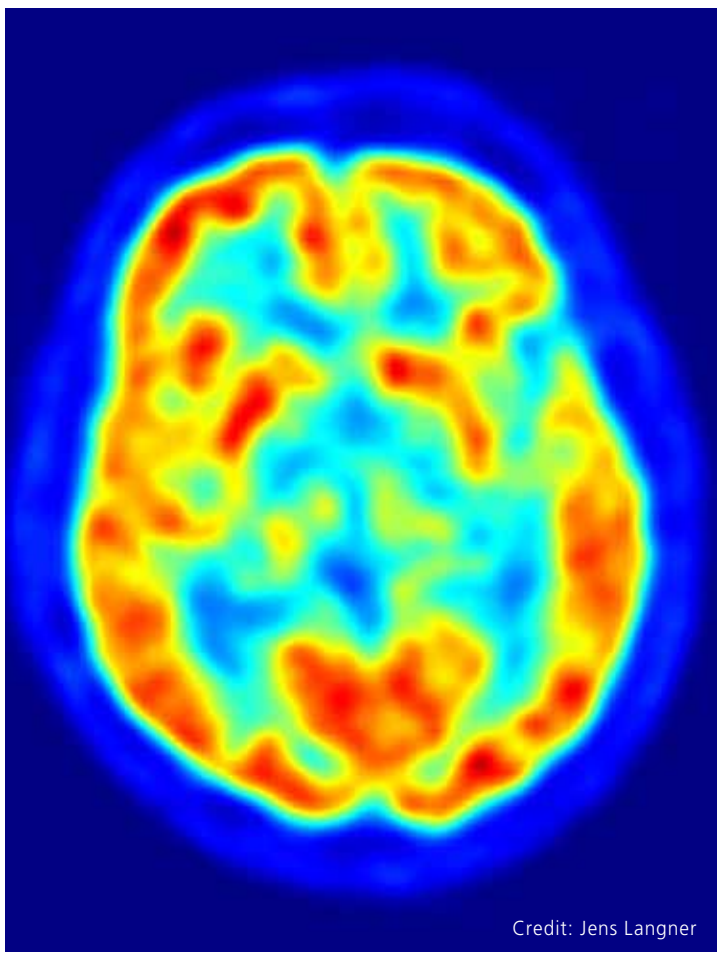
RESEARCH NEWS

What is creativity, and how can we understand it?

Creativity is a key ingredient of both science and art, but how much can scientific inquiry tell us about creativity?

"Science can study creativity, but creativity is also central to the scientific process; it is useful to understand both directions of this interaction," says SFI Professor and Chair of the Faculty Jennifer Dunne, who is co-organizing a working group this summer with Bill O'Brien and Sunil Iyengar of the National Endowment for the Arts.



Credit: Jens Langner

The two-day gathering July 9 and 10, "The Nature of Creativity in the Brain," is the first formal collaboration between SFI and NEA. The group is examining creativity through the lenses of cognitive science, psychology, education, defense, healthcare, the arts, and neuroscience.

"There is mounting interest in these themes that spill out across different sectors and populations," says O'Brien. "If we're really trying to understand the brain, what can we learn from the nature of creativity? From an evolutionary standpoint, why is it here? From a psychological standpoint, how does it behave? From the point of view of artists, how does it feel?"

The group hopes, through discussion, to ascertain future directions for more focused research into creativity, and to identify questions SFI scientists and other researchers might pursue using computational and other approaches.

"We are looking for different kinds of deep synergies that can come about from integrating art, science, and technology under the broad topic of creativity in the brain," says Dunne. "Though SFI is a science institute, we are very broad in terms of studying complex systems, so it's a perfect place to bring together this amazing, diverse group of scientists and artists."

When the working group concludes, it will post an executive summary of its findings on the SFI and NEA websites. ■

RESEARCH NEWS

The frustration of spin glasses

Spin glasses are frustrating. Although the ideas have been around for decades and form the foundation of countless complex systems models, they have nonetheless resisted researchers' efforts to understand exactly how they work – something three SFI scientists hope to change starting with a five-day working group at SFI in July.

Spin models were originally introduced to study materials made up of tiny magnets with varying orientations – so-called spins – at the atomic scale. In a household fridge magnet, the "spins" prefer to be aligned, and that overall preference results in a magnetization useful for suspending a child's report card or grocery list.

But the picture is not always so simple: In spin glasses each spin prefers to align with some of its neighbors, while being anti-aligned with others. These conflicting interactions can leave a spin in a quandary: which neighbors should it agree with?

This frustration – that is the technical term – and researchers' frustration when trying to understand spin glass dynamics is not limited to magnets, says SFI Omidyar Fellow Ruben Andrist, who along with SFI External Professors Jon Machta and Helmut Katzgraber is organizing the working group.

"It is not just a [problem in a] single field," he says, citing examples in fields from quantum computing to voting models, where "frustrated spins" represent voters trying to decide between political parties. While there is inherent interest in solving such models, their complexity makes solving them very challenging, he says.

The working group will lead off with a basic question, Andrist says: "Can we even make a statement about how computationally complex a problem typically is?" In the worst case, spin glass problems are among the hardest to solve, he says, but the typical case could be easier, and figuring that out would already be a step forward.

The group will review several recent developments in the field and, they hope, develop measures of difficulty that will aid researchers' efforts to study spin glasses across disciplinary boundaries. ■

> *Statistical mechanics*
continued from page 1

In May, SFI External Professor Stefan Thurner convened a workshop with the help of two seminal figures in the field – SFI External Professor Constantino Tsallis and SFI Distinguished Fellow Murray Gell-Mann – to revisit those ideas and assess the state of a field that some of the participants helped create.

The issue, Tsallis says, is the set of assumptions physicists make in conventional statistical mechanics. When studying a gas, for example, the usual thing to do is nearly ignore the possibility of collisions between particles. Often that assumption works out fine, but it fails, for example, when working with elementary particles in high-energy colliders – or when studying language, for that matter, where like the interactions of subatomic particles, grammar and semantics make some combinations of words more sensible than others.

Tsallis first addressed that problem in 1988 with the first example of what came to be known as generalized or nonextensive statistical mechanics, where nuclear forces, grammatical rules, or other interactions change how the information in a system scales with its size. Gell-Mann was an early proponent of the approach, and by 2002 the pair organized a workshop to see "if Nature likes that idea too," Tsallis says.

Recent progress on generalized statistical mechanics and related ideas in information theory and machine learning made this the right time for a status update, Thurner says. Since the 2002 workshop, concepts that Tsallis and others developed have been applied to biology, social science, and ecology, not to mention physics.

Still, many questions remain. "One recurrent topic of the workshop was the question 'to what extent is generalized statistical mechanics *the* theory behind specific models" in complex systems, Thurner says. In some cases, it may only be a good approximation, while in others, such as with path-dependent but still random processes, the theory may turn out to be exact, he says. ■

ing entanglement of particles. This year, two research teams have added strength to the then-dismissed idea, according to an April 16 article in *Quanta* magazine.

In the Computer Science Teacher's Association blog on April 29, SFI Learning Lab Director Irene Lee describes a new SFI-inspired GUTS y Girls curriculum and encourages readers to form partnerships with social science teachers.

An article in *The Epoch Times* on April 26 describes how noninvasive satellite monitoring might help improve the chances of survival of "uncontacted" indigenous human groups, citing an April 21 paper in *The American Journal of Human Biology* co-authored by SFI's Marcus Hamilton.

An article in *The Atlantic* on April 17 posits 11 reasons the United Nations should make cities the focus of its sustainable development goals, mentioning SFI research among the evidence.

In a two-part article in *Science News* on the 20th anniversary of Shor's algorithm, writer Tom Sigfriend recalls an SFI meeting in 1994 that he says captured the thoughts of the world's best quantum thinkers at a key time in that field's history.

Cities are the greenest possible way to live together, and perhaps the only way we can blunt climate change, according to an April 11 article in *The Guardian* that cites SFI cities & urbanization research.

SFI Online

Multimedia content available at ***www.santafe.edu***

Video: SFI Professor Luis Bettencourt reviews recent research in the science of cities, peering down to the level of neighborhoods and their people for insights about human development. SFI 2014 Community Lecture

Video: SFI External Professor Daniel Dennett asks: if free will is an illusion, should we conclude that we don't need real free will to be responsible for our actions? SFI 2014 Community Lecture

Video: SFI Science Board member Deborah Gordon explains how ant behavior, her lifelong research passion, can help us better understand brains, cancer, and the Internet. TED talk

Video: SFI External Professor Mark Newman asks what the large-scale mathematical structures of networks can tell us about many kinds of complex systems. SFI Science Board Symposium presentation

Video: SFI External Professor Brian Enquist describes a project to develop a geographic inventory of forest assets for western North America and model how climate change scenarios might affect species distribution. Aspen Ideas Festival presentation

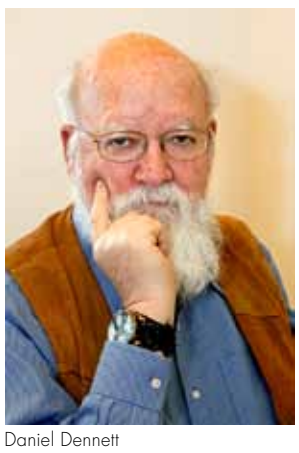
Video: SFI Professor Cris Moore explores emerging methods for detecting clusters of related data points in large network datasets. SFI Science Board Symposium presentation

RESEARCH NEWS

Rival science camps find common ground

While the movement toward an evolutionary perspective on human culture has been gaining traction over the past decade, the field of cultural evolution is a divided house.

The disagreements – mainly between two factions – hinge on a working definition of culture itself and how cultural information is transmitted.



Daniel Dennett

In an effort to bridge those differences, SFI External Professor Daniel Dennett held a working group, "Perspectives on Cultural Evolution," at SFI in May. The group comprised many of the field's leading theorists and experimentalists – including SFI Cowan Chair Rob Boyd.

That the two rival camps emerged from the working group more in agreement than in disagreement Dennett and Boyd attribute to the collaborative spirit of SFI in general, to the fact that the gathering focused more on common cause, and to Dennett's unusual methodology.

After having participants send in what they'd written, Dennett asked them to rank whose work they'd like to introduce. "People usually read someone else's work with an antagonistic approach," he explains. "But here, they had to present someone else's work to that person. It brings out the best in people."

Boyd's three-member camp described the work of a group led by Dan Sperber. "We came away with a deeper appreciation of what they are trying to say – and the reverse was true as well," says Boyd.

Unlike other meetings of this nature, there will be no companion volume. But the summaries of the group each participant was asked to submit to Dennett will be posted online.

"It'll be a goldmine," says Dennett. "Cultural evolution may still be seen as being divided into camps. But from this point forward they'll also be seen as having much more in common than people had realized." ■

> ***Technology forecasting*** **continued from page 1**

Strumsky says, is that innovations and improvements at higher levels of the network percolate through the lower levels of the system and play a role in enabling technological change.

"If anyone in the larger trophic structure finds a new way to save costs, then I benefit too," she says.

Products that are very close to their natural resources, like coal, oil, and natural gas, get far less benefit from trophic improvements due to the short distance from their natural resource base. In contrast, rapid and consistent progress of many high-tech goods such as photovoltaics is a function of the length and complexity of their trophic structures.

This matches what we see in the real world, she says. "If you control for other factors, the price of coal hasn't changed since the late 1800s. But costs of photovoltaics have fallen by orders of magnitude since the 1970s."

Strumsky, SFI External Professor Doyne Farmer of Oxford University, and Jose Lobo of Arizona State University organized the working group, which is funded by an alternative energy grant from the U.S. Department of Energy, and by the Institute for New Economic Thinking and SFI.

The ultimate goal of the project, Strumsky says, is to develop quantitative forecasting methods that support improved decision-making in the allocation of research and development investments. ■

SFI SCIENCE BRIEFS

(Image: istockphoto.com)

Dinosaurs: Cold blooded or warm blooded?

It's a longstanding puzzle: Were dinosaurs lumbering cold-blooded animals or swift warm-blooded creatures? Neither, according to a June 13 paper in *Science* co-authored by SFI External Professor Brian Enquist. Rather, dinosaurs took a middle path between warm-blooded mammals, or endotherms, and cold-blooded reptiles, or ectotherms. The researchers estimated dinosaur growth rates from fossils, then derived metabolic rates from the growth rates.

Eight-century baby boom, crash offer population lessons

A June 30 paper in *PNAS* co-authored by SFI Science Board member and External Professor Tim Kohler sketches an 800-year baby boom among Native Americans in the southwestern U.S. starting around 500 A.D., followed by a crash, that Kohler says offers a warning sign to the modern world about population growth. Analysis of human remains from hundreds of archaeological sites enabled the researchers to assemble a detailed chronology of the region's Neolithic Demographic Transition – a shift from a hunter-gatherer way of life to an agrarian civilization. They find that birth rates in some areas during this period were so high they likely exceeded the highest in the world today. The subsequent depopulation starting in the mid-1100s might have been a result of drought and of the human population reaching the region's carrying capacity, Kohler suggests.

Aggressive greed's altruistic side

In many group-living species, high-ranking individuals who bully to get what they want annoy their group-mates, but their contribution likely is key to a group's success in conflict with other groups, according to a new study published March 26 in *Nature Communications* that modeled behavior to shed new light on the evolutionary roots of cooperation and group conflict. Former SFI Omidyar Fellow Laura Fortunato co-authored the paper.

Does individual experience play a role in ant colony success?

In a recent *PNAS* paper, SFI External Professor Hans Schellnhuber and collaborators model social animals' hunting, homing, and path-building behaviors and suggest that individual ants' ages, abilities, and experience play a role in the foraging success of the entire colony.

Can genotype networks further human population studies?

SFI External Professor Andreas Wagner is among co-authors of a recent paper in *PLOS ONE* that explores application of the concept of genotype networks in studies of human population genetics. Combined with the availability of larger datasets of sequencing data, genotype networks represent a new approach to the study of human genetic diversity that looks to the whole genome and goes beyond the classical division between selection and neutrality methods, the authors write.

People think about health more on Mondays

A recent analysis of health-related Google searches finds that searches for health topics are far more frequent near the beginning of the week than later in the week – a pattern that might help devise strategies for improved public health. SFI Omidyar Fellow Ben Althouse is a co-author of the study, published April 21 in the *American Journal of Preventive Medicine*. ■

Yoav Kallus
The geometry of matter

The geometry of matter – how different polyhedral units could form substances of various material properties – fascinated Greek philosophers.

Today, nanotechnology's promise to make substance from scratch confers new import to questions such as "how many regular polyhedra can be packed into a given space?" The answers could lead to new materials that uniquely respond to pressure or reflect light, for example.

Yoav Kallus, a theoretical physicist with a penchant for mathematics, asks just these sorts of questions. As a PhD student at Cornell, Kallus developed an algorithm for finding the densest possible configuration of 3D tetrahedra using a simpler and more elegant repeating unit than any previous attempts.

"I think there are a lot of really interesting questions at the interface of physics and math that not a lot of people are paying attention to," Kallus says. "It's important to have a coherent theory for why structures form out of simple rules, why they sometimes fail to form, and how we can encourage them to form in the way we want."

While at SFI, Kallus will continue his study of ordered and disordered systems and explore how their statistical properties could be applied to more general complex systems.

He plans to join SFI on September 1. ■

Caitlin Stern
Why animals come together

In flocks, herds, prides, and human cities, sociality is a powerful phenomenon. Caitlin Stern, a behavioral ecologist, seeks to understand why animal groups form and evolve over time.

"I am fascinated by questions about the evolutionary implications of sociality," Stern says. She comes to SFI following a postdoctoral fellowship at the University of North Carolina, where she developed a novel mathematical model for the evolution of competition and social group size begun during her PhD studies at Cornell.

Her model differs from previous group-competition models in that it allows individuals to adjust their degrees of competition as they would in nature. "It's about adding some of the complexity of natural populations to our mathematical models so we can make better predictions about how social behavior evolves," she says.

After the extra variables were added, Stern's model showed that larger social groups feature less competition among individuals. This, she says, contradicts dominant views in evolutionary biology, but is supported by some empirical research.

While at SFI, Stern would like to develop more realistic models that incorporate heterogeneity in group size and rates of movement between groups.

"The way SFI allows researchers to interact across disciplinary boundaries will let me use the best approaches in science, not just in my own field," she says.

She plans to join SFI on September 1. ■

Justin Yeakel
Webs of complexity

Ecologist Justin Yeakel wants to know how the characteristic complexity of food webs emerges from simple behaviors, sometimes over millions of years.

"Modern food webs are complex systems," Yeakel says. "Where does this complexity come from? Is a modern food web similar to a paleontological food web, or were paleontological food webs very different?"

Yeakel's background is in paleoanthropology. While pursuing a PhD at UC Santa Cruz, he reconstructed the diets of mammals from both the modern Serengeti and the Pleistocene mammoth steppe by analyzing ratios of stable isotopes found in their bones.

He joins SFI following a postdoctoral fellowship at Simon Fraser University, where he researched the spatial dynamics of river ecosystems.

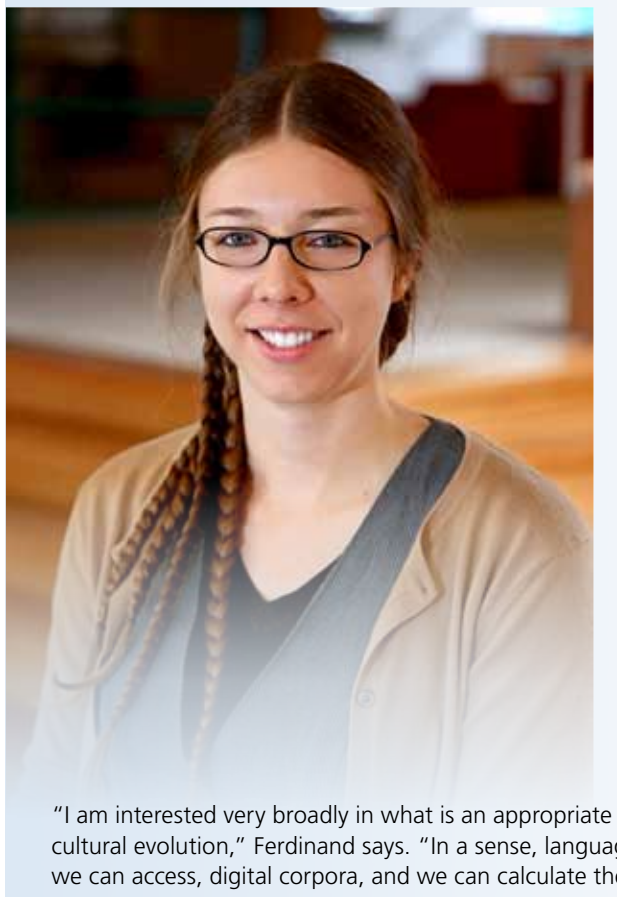
"All of these are examples of complex biological systems, describing how biomass flows on a network," Yeakel says. "You can study how these systems work using network theoretic approaches."

While at SFI, Yeakel wants to explore how the local constraints on an animal's behavior and dietary decisions impact the food web as a whole. "I'm interested in exploring the interplay between individual behavior and the larger communities we observe in nature," he says.

He also looks forward to collaborating with other scientists from diverse fields. "How similar, sometimes, the questions are," he remarks.

He joined SFI in June. ■

Vanessa Ferdinand
Cognition and culture



For cognitive scientist Vanessa Ferdinand, bygone expressions such as "mine eyes" and its modern equivalent "my eyes" provide windows into quantifiable structures of thought and culture.

Through language, Ferdinand explores the relationship between human cognition and cultural evolution. For her PhD at the University of Edinburgh, she used an artificial language learning task to model how some words fall out of usage in favor of synonyms. The process of eliminating variation from a language results from patterns in our cognitive structure, which is partly shaped by culture and language, she says.

"I am interested very broadly in what is an appropriate framework for understanding cultural evolution," Ferdinand says. "In a sense, language is discreet: we have the data we can access, digital corpora, and we can calculate the entropy of a synonym set."

While at SFI, she plans to use information theory to explore the co-adaptation of individual and environment. "When you do cognitive science research and neuroimaging, you see structural reorganization in the brain — different connectivity emerges when you teach someone a new task, like how to juggle," she explains.

"The structure of these culturally transmitted systems change, like in language," she notes. "So what I want to do is study these things in parallel to see if we can really understand cause and effect."

She plans to join SFI sometime this fall. ■

Laurent Hébert-Dufresne
How social systems grow

New SFI Postdoctoral Fellow Laurent Hébert-Dufresne wants to understand, through the lens of network theory, how social systems expand.

"By looking at the distribution of things like sexual activity or art production, we try to predict how likely the activity is to happen in the future based on our models," he says.

He recently completed his PhD at Laval University in Québec, his lifelong home. But he has spent time in New Mexico, collaborating with SFI scientists. He comes to SFI as part of a James S. McDonnell Foundation postdoctoral fellowship in complexity.

He's looking forward to developing his own project here at SFI, which he hopes will be a long-term study regarding network theory.

"What I would really like is to start doing the same thing I've been doing with disease propagation but more on social systems – looking at how ideas spread, how people come to consensus on network structure, etcetera," he says. "I feel like there is a place for me there."

Hébert-Dufresne notes the many parallels between disease and idea propagation and the network theory of social structures. He would like to explore how far science can push that analogy.

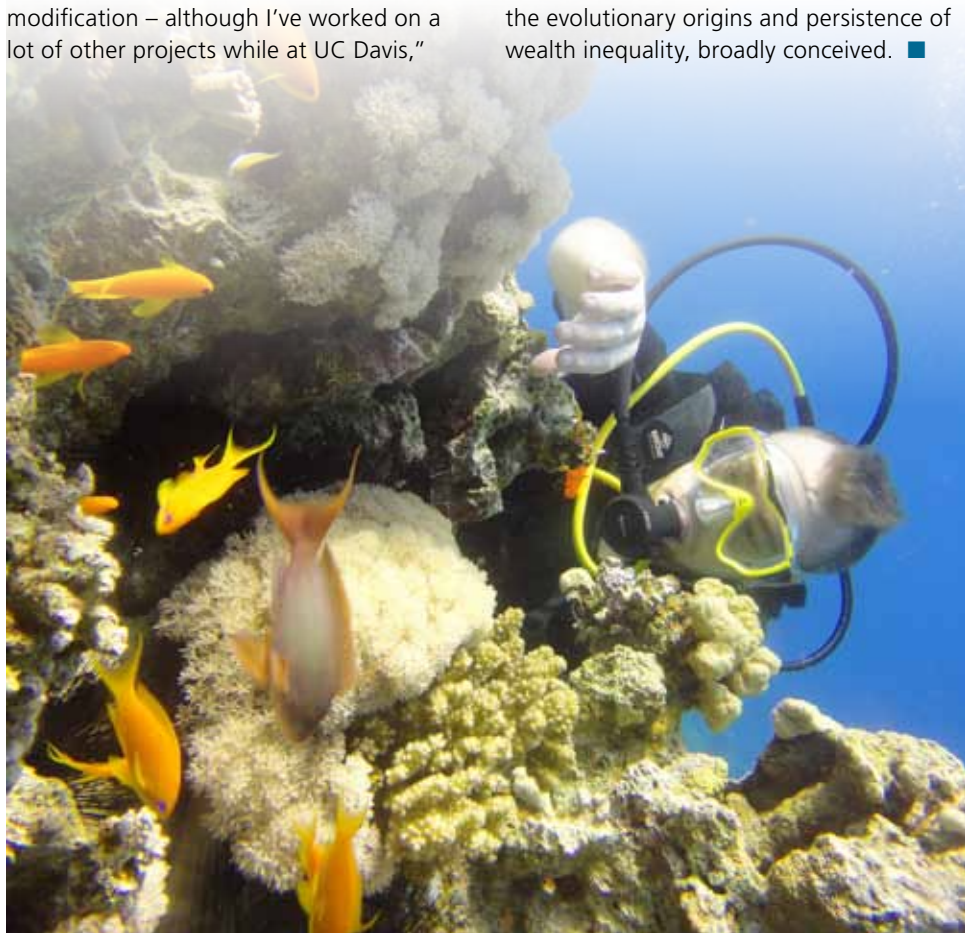
"You can become 'infected' with an idea," he says. "My question is: do we see the equivalent of disease mutation in ideas? Can we reach similar conclusions drawing from what we know about diseases into predicting social outcomes?" ■

Cody Ross
Satisfying interests through anthropology

New SFI Postdoctoral Fellow Cody Ross' research includes everything from evolutionary immunogenomics to cultural anthropology, but it is computer modeling and Bayesian statistics he finds most fascinating. He uses anthropology as a vehicle to satisfy his many interests.

"My dissertation focused on the cultural and evolutionary dynamics of female genital modification – although I've worked on a lot of other projects while at UC Davis," Cody says. "My research is pretty wide-ranging and integrative." He believes he will feel very much at home within SFI's community of like-minded thinkers.

Ross says he plans to expand the statistical and modeling side of his research at SFI. He arrives at SFI in August, and will work with SFI Professor Sam Bowles and Monique Borgerhoff Mulder on a project concerning the evolutionary origins and persistence of wealth inequality, broadly conceived. ■



Andrew Berdahl
How animals find their way

Physicist-turned-ecologist Andrew Berdahl studies collective behavior, specifically how groups of animals navigate during their annual migrations. He combines computer modeling with empirical data.

In his recent PhD work at Princeton, Berdahl discovered that a salmon's ability to return to its natal stream depends on the size of the school it travels in: more fish, more accuracy.

"If animals' abilities to find their way is dependent on group size, there could be population thresholds below which they won't be able to migrate at all," Berdahl explains. "So there are ramifications for conservation."

In a recent laboratory experiment, he and his colleagues were surprised to find that fish use "a much more simple and robust" navigation mechanism than they had originally imagined. "The more real systems we look at, the more we find these neat lessons 'learned' by evolution," he says.

At SFI, he hopes to develop more causal and predictive theories by working with increasingly sophisticated datasets. "Now that we're getting individual trajectory data from video, remote sensing, and tagging technology, we can apply information-theoretic measures to these trajectories to pull out or suggest things like causality," Berdahl says. "I think this has the potential to reshape the way people understand animal swarms."

He plans to arrive at SFI September 1. ■

Josh Grochow
Computation meets complexity

Where computation meets complexity, expect to find Joshua Grochow. With a background in math and theoretical computer science, Grochow wants to apply rigorous mathematical techniques to real-world complex systems and pursue problems at the frontiers of theoretical computer science.

"I recognize that although I do very theoretical things, there are really important problems today that are not theoretical," Grochow says. "We have problems of overpopulation and climate change and poverty and global epidemics. I look forward to working with people who work on those topics and bringing some heavy math tools to bear on them."

Grochow holds a PhD in computer science from the University of Chicago, as well as a master's degree in computational biology from MIT.

He comes to SFI following a postdoctoral fellowship at the University of Toronto, where he has devoted much of his research to a nascent branch of mathematics called geometric complexity theory, whose tools, he anticipates, will prove useful for studying other complex systems.

"I like to think of even an individual algorithm as a complex system," Grochow says. "Oftentimes people study complex systems using a computer simulation, so what they're really looking at is the behavior of an algorithm. In that sense, anything you can ask about computational complexity is a question about complex systems."

He joined SFI in June. ■

Analysis: Regardless of our city's size, we all live in 'villages'

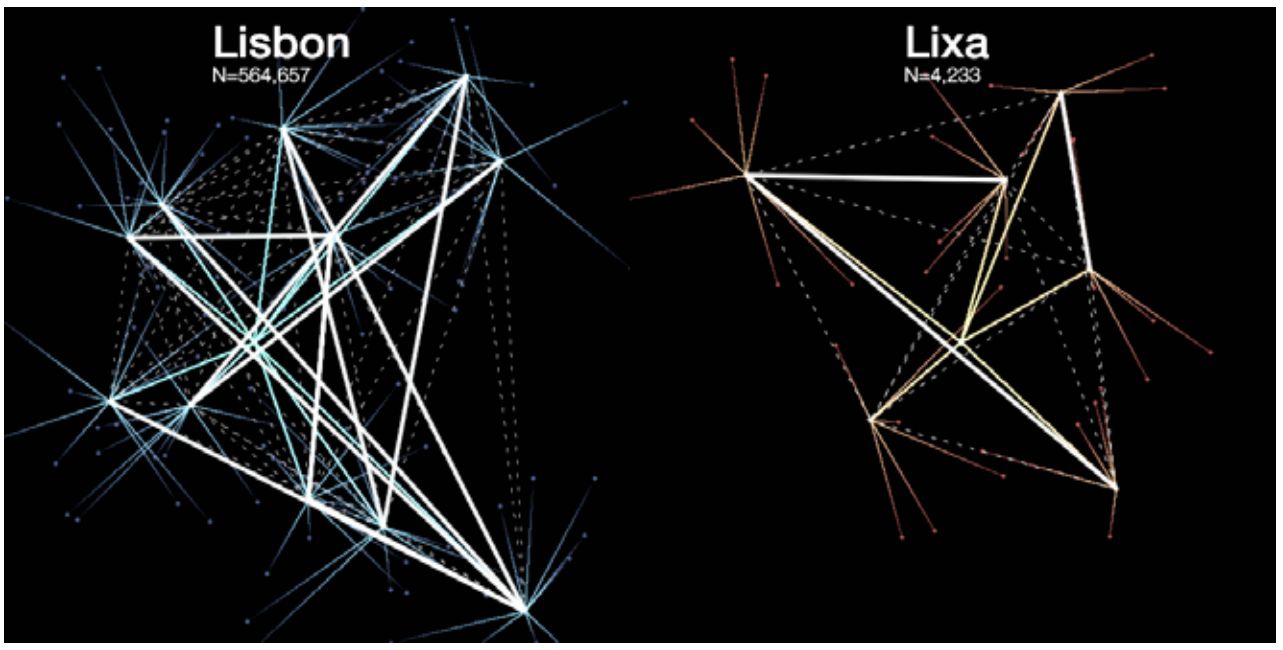
Intuitively, the close community spirit of village living and the crowded bustle of the big city suggest very different qualities of social life. A paper published July 2 in the *Journal of the Royal Society Interface* finds, however, that the social networks of city dwellers are not so different from those of village dwellers.

To examine social relationships of people living in towns and cities in Portugal and the UK, researchers from SFI, the MIT Senseable City Lab, British Telecommunications, and Orange Labs obtained a dataset comprising the majority of landline telephone calls made in the UK during a one-month period in 2005, and another dataset of millions of mobile phone calls in Portugal during a 15-month period in 2006 and 2007. Together, these two datasets represent several billion phone calls.

The researchers then constructed networks of phone interactions for each town in the UK and Portugal, with each individual user represented by a node, and connections between them indicated by a link.

The team's analyses of the resulting network data revealed that the number of calls made by an individual, as well as his or her total number of connections, depends on the town's size according to a mathematical relation: the larger the town you live in, the more people you call and the more calls you make. Interestingly, this relation is 'superlinear,' meaning that on average, as town size doubles, the total number of social interactions will more than double in a predictable way.

The team also found, however, that the group clustering of social circles (the odds that your friends mutually know one another) does not change with city size, regardless of whether you live in the five square-mile town of Lixa in northern Portugal or the bustling capital city of Lisbon.



Social networks derived from mobile phone data in Portugal: An average urban dweller of Lisbon has approximately twice as many contacts than an average individual in the rural town of Lixa. However, the odds that an individual's contacts mutually know one another remains largely constant. (Image: Kael Greco, MIT Senseable City Lab)

The findings point to the conclusion that human beings living in small towns and large cities alike instinctively form tight social communities. But if you live in a small community, your social circle is more or less determined by those who live around you, whereas in a large city you have more freedom to select which of the thousands of people around you will constitute your social circle.

"It seems that even in large cities we tend to build a tightly-knit community, or 'village,' around ourselves", says Carlo Ratti, director of the MIT Senseable City Lab. "In a real village, connections might be defined by proximity, while in a large city we can elect a community based on affinity, interest, or sexual preference, for example."

This points to what is fundamental about a city, says SFI Professor Luis Bettencourt who, along with SFI Distinguished Professor Geoffrey West, leads SFI's cities and urbanization research team.

"People tend to think of cities as people, buildings, roads, pipes, and so on," Bettencourt says. "But at a more fundamental level, cities are really about connections. These connections form networks of people and organizations that enable the production of all outcomes of civilization, from modern economies and fast innovation to complex bureaucracies and political institutions."

"That social interactions per person increase with city size begins to explain how so many socioeconomic quantities, from GDP to violent crime, scale superlinearly," he adds. "We had developed theory that predicts the superlinear growth of social connections in the way we observe here, but this is the first time that we can observe this phenomenon directly and explore it in detail." In a 2013 paper in the journal *Science*, Bettencourt derived a series of mathematical formulas that describe how cities' properties vary in relation to their population sizes.

SFI Postdoctoral Fellow Markus Schläpfer of MIT's Senseable City Lab, the paper's corresponding author, said the team's findings have important implications for the way information and ideas diffuse throughout a city. Ultimately, this may also help researchers understand phenomena such as the prevalence of certain contagious diseases.

"This was an incredible opportunity, made possible by today's widespread use of mobile communication technologies", he says. "Data of this type keep getting better and better. It will be extraordinary to use them in the future to see how cities around the world reproduce the patterns we observed for Portugal and the UK, and watch fast-growing cities develop as immense social networks. It throws open lots of possibilities to study the organization and dynamics of entire cities."

Co-authors of the paper, titled "The scaling of human interactions with city size," include Schläpfer, Bettencourt, West, Ratti, Mathias Raschke of Raschke Software Engineering, Sébastian Grauwin of the Senseable City Lab, Rob Claxton of British Telecommunications, and Zbigniew Smoreda of Orange Labs. The project was developed as part of Ericsson's "Signature of Humanity" project. ■

CSSS 2014: Many perspectives on the problems of modern times

On Monday, June 9, some 60 early career scholars from around the world gathered on the campus of St. John's College in Santa Fe to embark on a four-week journey through complexity.

First on the microphone was SFI External Professor Sander Bais, Director of SFI's Complex Systems Summer School (CSSS), who welcomed the students and called attention to the diversity of the participants.

"Overall we have a nice coverage of the earth," said Bais. "Twenty nationalities, and twenty scientific backgrounds, a rich diversity indeed. There is fertile ground here to communicate and learn from each other."

The participants, most of them graduate students and postdocs, participate in four to five lectures per day on topics ranging from entropy to evolution, from molecular biology to anthropology, all grounded in the fundamentals of physics, mathematics, and computer science, and most taught by SFI faculty. The program is accompanied by student group projects, presented to the SFI community during the final week of the school.

Bais, a professor with the University of Amsterdam's Institute for Theoretical Physics, has been director of CSSS for three years. He draws on his own rich background in physics, mathematics, and education to make the school relevant to a broad spectrum of bright minds.

"It's very stimulating to have all these young people eager to learn all these new techniques and perspectives on the problems of modern times," he says.

Anna Olson, a graduate student in computer science from the University of Chicago and a 2008 SFI REU alumna, says the first day of the summer school was intense due to the volume of information, but she was happy to be a part of it.

"Lots of lectures, a lot of people, just a lot of information to take in, but it's all very exciting," she says. ■

Complex Systems Summer School students try out a sand table used by CSSS speaker Stephen Guerin, president of RedfishGroup in Santa Fe, as an interactive map to help emergency responders visualize how fire can spread in a landscape. (Credit: InSightFoto)

Creativity in art & science

SFI's Valerie Plame Wilson (left), Eastern Band of Cherokee artist Shan Goshorn (center), and SFI Faculty Chair Jennifer Dunne got together for a photo following a unique event in Santa Fe on Saturday afternoon, May 31. In a broad discussion moderated by Plame, Goshorn and Dunne explored the creative process from their perspectives as an artist and a scientist. "It turns out that the concepts of interconnectedness and 'webiness' lay at the heart of both Shan's basketry work and my ecological network research," says Dunne. "This informs her artistic vision as well as my scientific understanding of complex interactions." Some 140 people attended. It was the third annual discussion in the Chaos to Complexity series sponsored by SFI and the Museum of Contemporary Native Arts (MoCNA). (Credit: David Halpern)

Nihat Ay joins SFI's resident faculty

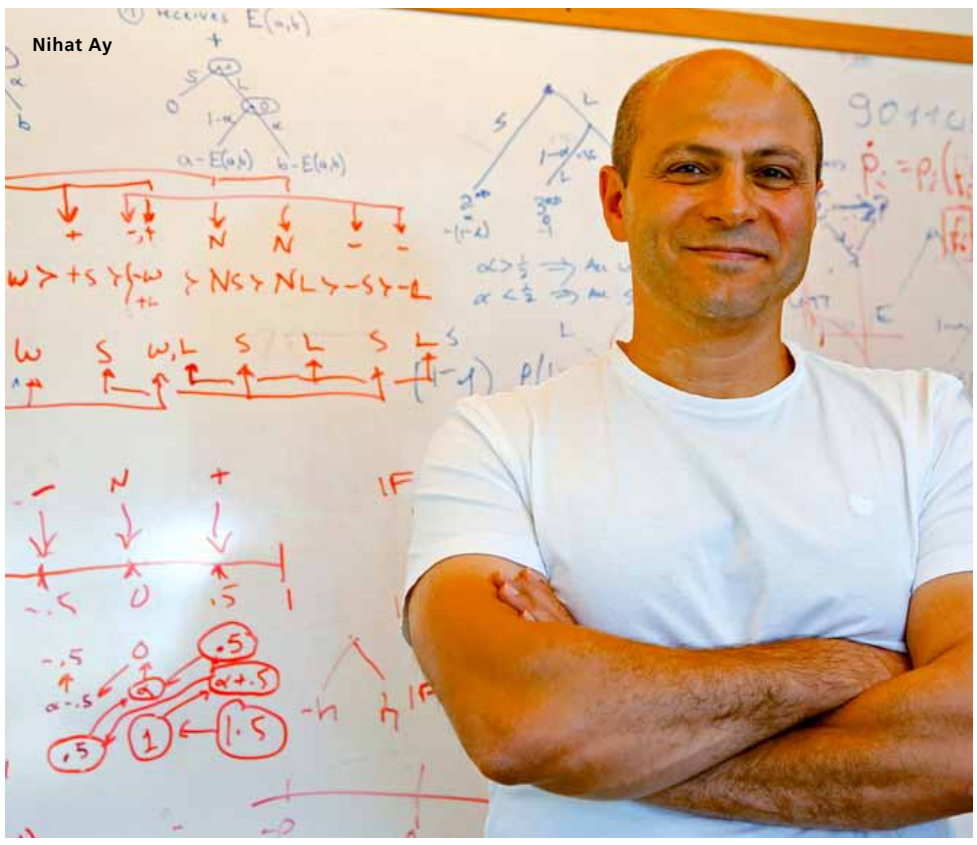
Mathematician Nihat Ay joined SFI's resident faculty on July 1, 2014.

"Nihat brings training in mathematics as well as deep expertise and wide-ranging curiosity to topics at the intersection of information theory, embodied cognition, robustness, and quantitative theory of causality," says SFI Chair of Faculty Jennifer Dunne. "His ability to formalize fundamental aspects of empirical science is outstanding, and he is deeply committed to complex systems research. As a former SFI postdoc and external faculty member, he has already collaborated with a diverse set of SFI scientists."

Ay will spend three months of the year at SFI and nine months in his current position as leader of the Information Theory of Cognitive Systems group at the Max Planck Institute for Mathematics in the Sciences in Leipzig, Germany.

"SFI is known as *the* institute for complexity science," Ay says. "I am confident that, based on 30 years of excellent research, SFI will play a leading role in integrating existing approaches and studies into one unified theory of complexity. Such a theory will require advanced analytical tools and, in particular, mathematics. Therefore, I see my research on complexity more than ever well placed at SFI."

Ay has a long history studying topics close to SFI's interests. As an undergraduate, he wrote a thesis on the geometry of the Amari-Hopfield model, an early neural network model of memory. He continued studying neural networks at Max Planck and earned a mathematics PhD at the University of Leipzig in 2001 with a thesis on information geometry with applications to complexity theory. He came to SFI as a postdoctoral fellow in 2003 and has been in his current position at Max Planck since 2005.



Nihat Ay

Recent faculty, board appointments

SFI President Jerry Sabloff has approved five-year resident faculty re-appointments for Geoffrey West (full-time, beginning August 1) and Sam Bowles (part-time, began July 1).

Seven new external faculty members have been selected. Their three-year appointments began July 1, 2014. They are:

- Simon DeDeo, Assistant Professor, School of Informatics & Computing, Indiana University, and former SFI Research Fellow and Omidyar Fellow
- Ross Hammond, Senior Fellow in economic studies and Director of the Center on Social Dynamics and Policy, Brookings Institution
- Helmut Katzgraber, Associate Professor, physics & astronomy, Texas A&M University
- Mahzarin Banaji, Richard Clarke Cabot Professor of Social Ethics, Harvard University, and former SFI Cowan Professor
- Rob Boyd, Professor, School of Human Evolution and Social Change, Arizona State University, and former SFI Cowan Professor
- Ricardo Hausmann, Director, Center for International Development, Harvard University, and former SFI Cowan Professor
- John Padgett, Professor, political science, University of Chicago, and former SFI Research Professor

Two people have been selected to join SFI's Science Board. Their terms began July 1, 2014. They are:

- Margaret (Molly) Jahn, Discovery Fellow, Wisconsin Institutes for Discovery, Professor, Department of Agronomy and Laboratory of Genetics, Faculty Affiliate, Nelson Institute for Environmental Studies, Center for Sustainability and the Global Environment, University of Wisconsin-Madison, and Chief Scientist, Knowledge Systems for Sustainability, U.S. Department of Energy Oak Ridge National Laboratory
- Thomas Lovejoy, University Professor for Environmental Science and Policy, Biodiversity Chair at the Heinz Center for Science, Economics and the Environment, George Mason University ■

Help crowdsource the Complexity Explorer

The Complexity Explorer, an online education resource for learning about the science of complexity, could use your help. SFI External Professor Melanie Mitchell, faculty coordinator for the project, encourages visitors and registered members alike to submit new terms and definitions to the complexity glossary, links to resources relevant to complexity studies in web resources, or links to courses relevant to complexity studies in course syllabi. You can even help subtitle course videos and earn a Complexity Explorer T-shirt.

Visit the Complexity Explorer website for more about ways to get involved.

COMPLEXITY EXPLORER
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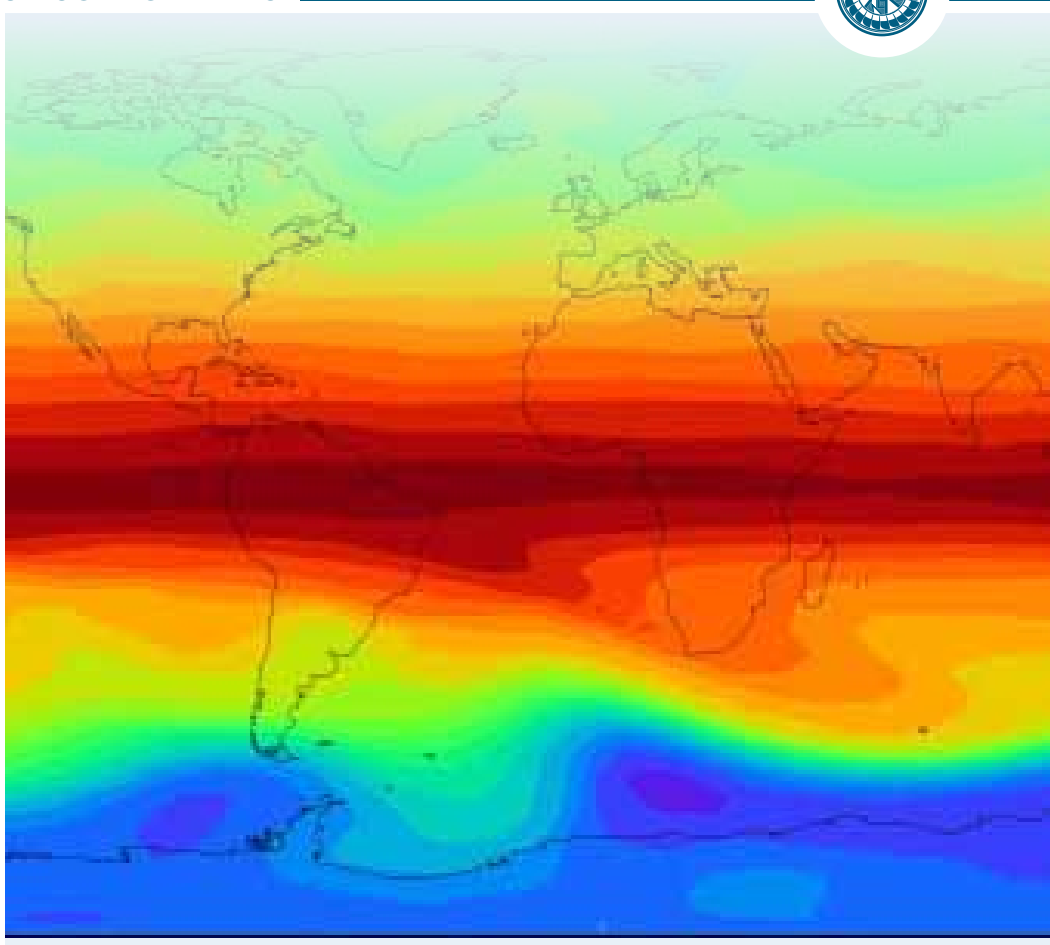


Distribution of methane in the stratosphere (Image: NASA GSFC Atmospheric Chemistry and Dynamics Branch)

New ways to think about greenhouse gases

An April 25 paper in *Nature Climate Change* by SFI External Professor Jessika Trancik and MIT collaborator Morgan Edwards notes that past methods of accounting misvalue the relative contributions of methane and carbon dioxide to climate change. A more nuanced view of the long-term effects of methane suggests a second look at policies intended to reduce the climate effects of greenhouse gas emissions.

Ambiguous words probably make communicating easier

As counterintuitive as it may seem, ambiguity in language, including words with multiple meanings, actually makes communicating easier and could be an inevitable consequence of a language's evolution, according to an SFI working paper by External Professor Ricard Sole and Pompeu Fabra University physicist Luis Seoane, who used computer simulations to evolve vocabulary networks until they reached optimal states. When speakers' and listeners' needs were perfectly balanced, the authors note, optimal languages evolved that followed Zipf's Law – some ambiguous words, but mostly terms with single meanings.

Geoglyphs in Peru likely marked cultural event sites

An archaeological site in Peru features mounds and linear geoglyphs likely used to mark the summer solstice and other cultural activities in an ancient society, according to a May 5 *PNAS* study co-authored by SFI External Professor Charles Stanish.

Climate change will shift malaria to higher elevations

In a March 6 paper in *Science*, SFI External Professor Mercedes Pascual and collaborators show that malaria creeps to higher elevations during warmer years, suggesting that climate change will bring the mosquito-borne disease to higher, more densely-populated regions in Africa and South America – and outbreaks likely will be more severe in part because the newly exposed populations in these areas lack protective immunity.

Variable distributions for systems at the edge of chaos

A new paper co-authored by SFI External Professor Miguel Fuentes shows that the distribution of the variables of dynamical systems at the edge of chaos has a very different shape than previously reported. The paper appeared in the *European Physical Journal B* in February 2014. ■

SFI Distinguished Fellow Murray Gell-Mann will receive the 2014 Helmholtz Medal, awarded by the Berlin Brandenburg Academy of Sciences and Humanities, for his research in particle physics. The first Helmholtz Medal was awarded in June 1892 to the physicists Robert Bunsen and Lord Kelvin, among others. It is the highest honor awarded by the academy in recognition of outstanding scientific achievements.

SFI Science Board member Montgomery Slatkin is among 84 new members of the National Academy of Sciences. The NAS recognizes achievement in science by election to membership, and – with the National Academy of Engineering, Institute of Medicine, and National Research Council – provides science, technology, and health policy advice to the U.S. federal government and other organizations.

SFI External Professor Mark Newman has been awarded the 2014 Lagrange Prize for research achievements in the sciences of complexity. Organized since 2008 by the Institute for Scientific Interchange Foundation and CRT Foundation, the 50,000 Euro prize is given for "outstanding scientific contributions to the field of complexity and complex systems in all disciplines." Past SFI-affiliated winners include W. Brian Arthur and Duncan Watts.

SFI External Professor Andreas Wagner has been elected to the European Molecular Biology Association, a prestigious transnational academy of life sciences, for his research in the evolution of biological systems from genomes to complex molecular networks. The 106 new members for 2014 include 50 scientists who have made exceptional contributions in the fields of neuroscience, ecology, and evolution. ■

SANTA FE INSTITUTE
New Science. New Horizons.
1984-2014

Above: Bayes' Thereom

People-driven for three decades

The Santa Fe Institute is, above all else, a collection of people – from our visionary founders, to the young scientists who spend formative time here under the guidance of world-class mentors, to the middle school students who experience their first sparks of scientific passion through our educational programs. To understand SFI's impact, you need look only at the people who have passed through this institution, and what they've achieved since then.

Take our Omidyar Fellows, for example. Established by Pam and Pierre Omidyar in 2008, SFI's Omidyar Fellowship provides some of the world's brightest young scientists with the intellectual freedom to ask the big questions they're most passionate about.

Omidyar Fellows have come from disciplines spanning the sciences, and they spend their time here not only advancing their own research interests but also collaborating with peers and mentors on theirs. Omidyar Fellows are here for a relatively short time (up to three years), but they emerge from the experience prepared to take their places among the next generation of complexity thinkers.

Many past Omidyar Fellows have gone on to top positions in major academic institutions around the world. Others are building new tools that apply the lessons of complexity science to critical societal challenges. Caroline Buckee (2007-2010), for example, is at Harvard University's School of Public Health studying the spread of malaria and gaining important insights with the potential to transform public health. Jessika Trancik (2005-2009) is at MIT evaluating new approaches to adoption of low-carbon energy technologies that help address the challenges of climate change. And Nathan Eagle (2007-2010) has founded Jana, an innovative global company that is developing a mobile platform that taps the expertise of emerging-market consumers while providing much-needed income in the developing world. These are but a few examples demonstrating the power of the Institute and the Omidyar Fellowship experience.

Omidyar Fellows are just one group within our diverse SFI community, built around an unwavering commitment to asking – and seeking to answer – some of mankind's most pressing questions. As an SFI supporter, you are also part of this unique community, and by backing the Omidyar Fellowships and our other programs, you're helping ensure that our community and our influence continue to grow – one person at a time.

Best regards,

Nancy Deutsch, Vice President for Advancement

SFI@30
MY STORY

Nathan Eagle
Co-founder and CEO, Jana
Omidyar Fellow 2007-2010, Santa Fe Institute

"My postdoc was an incubation period. I actively made efforts to be intellectually promiscuous at SFI – becoming enamored with all sorts of ideas, many good and some laughably bad. Ultimately, the exposure to clever people and a diversity of ideas provided the direction I needed to develop a technology capable of instantly putting money into the pockets of 3.48 billion people. Now with the responsibilities and burdens associated with running a company, I do find myself reminiscing about that unique time of responsibility-free idea generation. Are we allowed to reapply?"

New Science. New Horizons.

CAMPAIGN NEWS – SFI'S OMIDYAR CHALLENGE

Through the SFI Omidyar Fellowship, we are identifying the most promising early career scholars working on important problems and providing them with the skills, opportunities, and resources to become tomorrow's leaders.

Gifts supporting the Omidyar Fellowship are matched dollar for dollar by Pierre and Pam Omidyar through the Santa Fe Institute's Omidyar Challenge Campaign. By contributing to the Omidyar Challenge, you double your giving power.

We still have nearly $70,000 to raise by the end of 2014, and almost $800,000 between now and the end of the Campaign to meet the challenge established by the Omidyars.

To date, SFI's 30th anniversary campaign – New Science. New Horizons. – has raised more than $22 million toward our $30 million goal.

Other opportunities to support SFI include:

- President's Circle Member: $1,000 per year – Annual giving club with special programming for members.
- Science on Screen series sponsorships: $2,500 for shared recognition during the 2014/2015 series.
- Education program scholarships: $3,500 will fully fund a deserving complexity scholar for 2015.

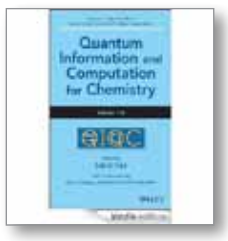
There also are opportunities to establish a permanent legacy, from named buildings and open spaces to endowed funds supporting science, education, and outreach. We welcome multi-year commitments and gifts of appreciated assets to fund your chosen program. Contact the Office of Advancement at 505.946.3678 to discuss how you can help us attain new horizons.

July / August 2014

UPDATE

SANTA FE INSTITUTE

NEW BOOKS BY SFI AUTHORS



Quantum Information and Computation for Chemistry: Advances in Chemical Physics Volume 154 (John Wiley & Sons, 2014) edited by SFI External Professor Sabre Kais explores the latest research findings, applications, and directions in quantum computation and quantum information that are related to or intersect with key topics in chemical physics. Expert reviews address both what chemistry can contribute to quantum information and what quantum information can contribute to the study of chemical systems, surveying both theoretical and experimental quantum information research within the field of chemical physics.

Starting Up Silicon Valley: How ROLM Became a Cultural Icon and Fortune 500 Company (Emerald, 2014) by Katherine Maxfield tells the story of how ROLM Corporation went from a four-person startup operation headquartered in a prune-drying shed to one of Silicon Valley's most important companies – and set the benchmark for a company culture that was very different from that of corporate America. ■

Upcoming community events

SFI Community Lecture - Is time travel possible? Testing the 'Grandfather Paradox.' Wednesday, July 16, 7:30 p.m., James A. Little Theater (1060 Cerrillos Road). Time travel is a science fiction staple, inspiring the plots of countless books, movies, and Star Trek episodes. But while basic physics allows for the possibility of moving through time, practical concerns like the "Grandfather Paradox" – in which a traveler jumps back in time, kills his grandfather, and therefore prevents his own existence – seem to stand in the way. Self-described "quantum mechanic" and SFI External Professor and Science Board member Seth Lloyd looks at an alternate mode of time travel that eliminates any events that could later prove paradoxical, making this phenomenon both theoretically possible and creatively irresistible, whether you're an astrophysicist, science fiction writer, or daydreamer.

SFI Community Lecture - The joy of x: A guided tour of math. Wednesday, August 6, 7:30 p.m., James A. Little Theater (1060 Cerrillos Road). Viewed through the right lens, the universal language of math connects to literature, philosophy, law, medicine, art, business, and even pop culture and current events. It underpins every aspect of our lives, from finding the perfect romantic partner to understanding how Google works. Yet few of us understand math well enough to appreciate its beauty, prompting world-class mathematician Steven Strogatz to bring math to the masses through a regular *New York Times* column. Strogatz shares what worked – and what didn't – in his efforts to democratize math, providing compelling clues on how to connect future generations to this increasingly critical discipline.

SFI's 2014 Community Lectures are made possible through the generous support of Thornburg Investment Management. Lectures are free and open to the public, but seating is limited. To watch a lecture as it happens, visit SFI's YouTube page; participate in the discussion live on Twitter at #sfi_live. ■

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