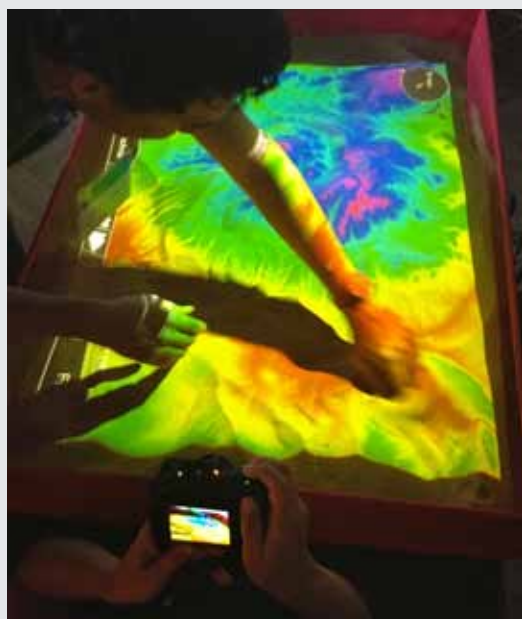




July / August 2013

# UPDATE



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## RESEARCH NEWS

### Where the physical and the algorithmic meet

Quantum computation holds the promise of fast computing and breakthrough decryption of sensitive information. An SFI working group in August brings together experts in quantum information to tackle questions at the frontiers of the field.

SFI Professor Cris Moore says the working group will focus on topics "at the intersection of what we can understand physically and what we can do algorithmically." Those problems, such as quantum cryptography and creating a quantum ana-

[> more on page 2](#)

## RESEARCH NEWS

### Getting inside the 'black box' of technology

Despite the importance of technological change as a primary driver of economic growth, economists have traditionally treated it as a single entity, described by a number commonly called "total factor productivity." But a group of SFI researchers believes technology progress is a far more complicated beast requiring a much richer description.

This summer SFI will host its first workshop exploring how best to study such progress. The August meeting, hosted by SFI External Professor Doyne Farmer and frequent SFI collaborators Eric Beinhocker, Deborah Strumsky, and Jose Lobo, will

[> more on page 2](#)

## Paper: Cities are part star, part network

Cities have long been likened to organisms, ant colonies, and river networks. But these and other analogies fail to capture the essence of how cities really function.

New research by SFI Professor Luis Bettencourt suggests a city is something new in nature – a sort of social reactor that is part star and part network, he says.

"It's an entirely new kind of complex system that we humans have created," he says. "We have intuitively invented the best way to create vast social networks embedded in space and time, and keep them growing and evolving without having to stop. When that is possible, a social species can sustain ways of being incredibly inventive and productive."

In a cover paper published June 21 in *Science*, Bettencourt derives a series of mathematical formulas that describes how cities' properties vary in relation to their population sizes, and

then posits a unified, quantitative framework for understanding how cities everywhere function and grow. His resulting theoretical framework predicts very closely dozens of statistical relationships observed in thousands of real cities around the world for which reliable data are available.

"As more people lead urban lives and as the number and size of cities expand everywhere, understanding more quantitatively how cities function is increasingly important," Bettencourt says. "Only with a much better understanding of what cities are will we be able to seize the opportunities that cities create and try to avoid some of the immense problems they present. This framework is a step toward a better grasp of the functioning of cities everywhere."

What has made this new view of cities possible are increasing opportunities in recent years to collect and share data on many as-

pects of urban life. With so much new data, he says, it's easier than ever to study the basic properties of cities in terms of general statistical patterns of such variables as land use, urban infrastructure, and rates of socio-economic activity.

For more than a decade, the members of SFI's Cities and Urbanization research team have used this wealth of new data to painstakingly lay the foundation for a quantitative theory of cities. Its bricks and mortar are the statistical "scaling" relationships that seem to predict, based on a city's size, the average numerical characteristics of a city, from the number of patents it produces to the total length of its roads or the number of social interactions its inhabitants enjoy.

Those relationships and the associated equations, models, network analyses, and

[> more on page 7](#)

## RESEARCH NEWS

### Great exaptations: Most traits emerge for no crucial reason

Exactly how new traits emerge is a question that has long puzzled evolutionary biologists. While some adaptations develop to address a specific need, others (called "exaptations") develop as a by-product of another feature with minor or no function, and may acquire more or greater uses later. Feathers, for example, did not originate for flight but may have helped insulate or waterproof dinosaurs before helping birds fly.

SFI External Professor Andreas Wagner and colleague Aditya Barve, both at the University of Zurich, decided to get a systematic handle on how traits originate by studying all the chemical reactions taking place in an organism's metabolism.

Starting with the metabolism of an *E. coli* that can survive on glucose as its sole carbon source, they subjected the complex metabolic chemical process to a 'random walk'

through the set of all possible metabolisms, adding one reaction and deleting another from it with each step. They kept constant the total number of reactions and the bacterium's ability to survive on glucose alone, but allowed everything else to change. Every few thousand steps they analyzed the altered metabolism's reactions.

They found that most metabolisms were

[> more on page 7](#)

(Image: Gabriel Garcia)



SFI Professor Luis Bettencourt’s June 20 cover paper in *Science*, “The Origin of Scaling In Cities,” prompted coverage in *Scientific American*, *Science News*, *Wired*, *The Atlantic-Cities*, and the *Santa Fe New Mexican*.

A June 11 article in *Science* online covers SFI Professor Jennifer Dunne’s recent paper in *PLOS Biology* that finds that including parasites in ecological datasets does alter the structure of food webs, but primarily due to an increase in diversity and complexity rather than the unique characteristics of parasites.

In a June essay in *Nautilus* magazine, “The Coin Toss and the Love Triangle,” SFI Research Fellow Simon DeDeo describes the roles both natural and social uncertainty play in our lives and how mathematics can help make sense of both kinds.

## Nonlinearities From the editor

Something special happens this time of year in Santa Fe...it rains in the afternoons. The high cumulus clouds building over the Sangre de Cristos shortly after lunch and the first thunderclap of the day are welcome heralds of moisture. A few storms won’t bring an end to this drought, of course, but I just have to say...Santa Fe is at its majestic best under a darkening monsoon sky. If you’re here, meet me in the parking lot at the first taps of rain on the Institute’s roof.

SFI’s postdocs – Omidyar Fellows and Postdoctoral Fellows – are amazing. They routinely work with today’s giants of science. They conduct original research of their own design. They contribute substantially to SFI’s work. In meetings and at tea they rarely adopt a passive role and often drive the discussions. Several have recently won their own research grants. After SFI they typically go on to join and even lead programs at top-tier academic institutions. I mention this because we are in one of those periods when many of our postdocs are moving on and others are moving in. In the coming months, we will say goodbye to at least as many as we welcome. Watch the September *Update* for a rundown. In the meantime, we’ll miss you (in no particular order) Laura, Scott, Simon, Rogier, Hyejin, James, and Charles.

Al Franken and Morgan Fairchild follow @sfi\_news on Twitter. So do more than 6,600 other people, not all of them celebrities, but plenty of them interesting. If you total up SFI’s followers on Twitter, Facebook, LinkedIn, Google+, and YouTube, you get nearly 15,000 people. I hope you’ll visit [www.santafe.edu](http://www.santafe.edu) and consider ways you might link up with SFI’s social media gang, and that you’ll share SFI with your friends or even ask a scientist a question.

Darragh Nagle, one of SFI’s co-founders, passed away on April 22. He was 94. Nagle was among a group of senior fellows at Los Alamos National Laboratory in the early 1980s who shared a disaffection with the stove-piped, bureaucratic, discipline-centric approach to science that had taken root at the funding agencies, federal labs, and academia – and whose vision for an independent, trans-disciplinary research center grew into the Institute. We owe him and the other founders a debt of gratitude. Thanks, Dr. Nagle.

– John German, [jdg@santafe.edu](mailto:jdg@santafe.edu)

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In the *Santa Fe New Mexican* on June 3, SFI Professor Paula Sabloff describes her anthropological research to understand Mongolians’ conception of and desire for democracy, also the topic of her recently published book. An abbreviated version of the article appears in *The Daily Beast* on June 12.

SFI Omidyar Fellow alums Caroline Buckee and Nathan Eagle are featured in a May/June *MIT Technology Review* article that explores the implications of cell phone big data, especially its promise for mitigating the spread of disease.

In the *Boston Globe* on May 13, Colin Hill, whose company GNS Healthcare is helping provide personalized medical treatment through genetic data analytics, says his par-

ticipation in SFI’s Complex Systems Summer School in 1996 contributed to his notion of merging chaos theory, big data, genetics, and health care.

An essay in the *Chronicle of Higher Education* on May 13 invokes the perspectives of several current and past SFI researchers – Daniel Dennett, Stuart Kauffman, and Harold Morowitz among them – on issues at the intersection of philosophy and evolution.

A May 9 column in *Scientific American* by SFI Distinguished Professor Geoffrey West asks what science is going to do with big data in the absence of a unified, conceptual framework for addressing questions of complexity.

In the *Santa Fe New Mexican* on May 6, SFI Omidyar Fellow Paul Hooper writes about his

research to understand the origins of certain traits that make us uniquely human, including the active role of both parents and grandparents during our unusually lengthy period of child development.

A feature in the May issue of *Smithsonian* traces the birth of the growing field of “quantitative urbanism” to a 2003 workshop at SFI and reviews the field’s progress toward an improved theoretical, mathematical understanding of cities.

On April 29 *The Daily Beast* notes a recent paper by SFI Research Fellow Simon DeDeo finding that Wikipedia’s remarkable accuracy comes from something larger than the sum of its written contributions – a sort of super brain comprising all of its contributors.

### RESEARCH NEWS

## Do parasites upset food web theory?

Parasites comprise a large proportion of the diversity of species in every ecosystem. Despite this, they are rarely included in analyses or models of food webs. If parasites play different roles from other predators and prey, however, their inclusion could fundamentally alter our understanding of how food webs are organized.

In a recent paper, SFI Professor Jennifer Dunne and collaborators test this assertion and show that including parasites in ecological datasets does alter the structure of food webs, but that most changes occur because of an increase in diversity and complexity rather than from the unique characteristics of parasites.

“Current food web models and theory were developed with data for free-living species,” says Dunne. “We wanted to understand whether including parasites alters network structure in unique ways, or if observed changes are consistent with the addition of any types of species and links to a food web.”

The group of researchers, which included parasitologists and food web ecologists, analyzed highly resolved datasets for seven coastal estuary and marine food webs. They compared three versions of each food web dataset: webs without parasites; webs that included parasites and all of their links to other species; and an intermediate case that included parasites but excluded the concomitant links between a predator and the parasites of its prey.

The team found that including parasites altered many measures of network structure,

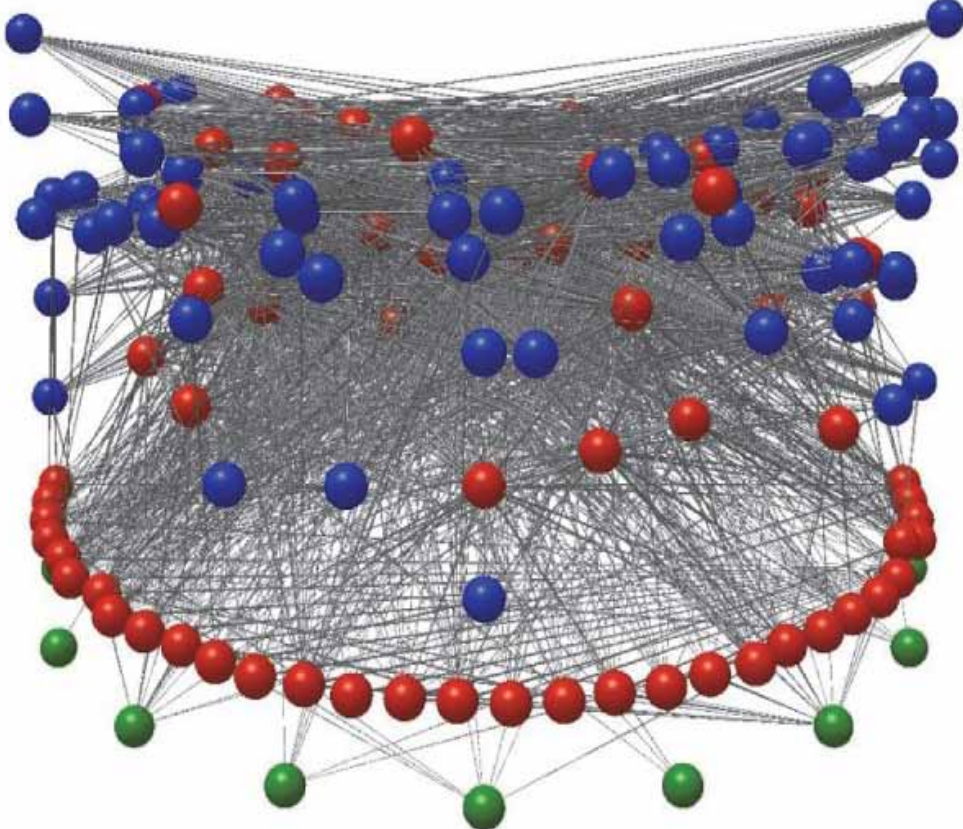
such as the distribution of feeding links per species, the average shortest feeding chain between pairs of species, and the proportion of species that are omnivores or cannibals. But a closer look suggested that most of these changes were generic effects of increasing the overall diversity and complexity of the network rather than effects attributable to the parasites’ unique roles in food webs.

However, the team did find two cases where parasites seem to play special roles that alter aspects of food web structure. One case is when a parasite is eaten along with its host. “The fact that predators incidentally feed on the parasites of their prey can alter certain patterns of interactions among species,” Dunne says.

The other case appears to result from the complex life cycles of many of the parasites in these food webs. Parasites can shift hosts in a dramatic fashion, for example by starting out with a cricket as a host, but later requiring a fish host. This results in a more structurally complex feeding niche than is seen for most free-living predators.

“Our research extends the generality of food web theory and provides a more rigorous framework for assessing the impact of any species on trophic organization,” says Dunne. “However, it also reveals limitations of current food web models when they are applied to the more diverse and highly resolved data that researchers are increasingly compiling.”

Their paper appeared in *PLOS Biology* on June 11. ■



A network of 4,671 feeding interactions among 68 parasites (in blue) and 117 free-living taxa (green = primary producers and detritus, red = consumers) in the food web of Estero de Punta Banda, Baja California, Mexico. The vertical axis is trophic levels. Image produced by Jennifer Dunne using Network3D software.

### > Quantum computation continued from page 1

log of probabilistically-checkable proofs, “are perfect for SFI because they’re in the overlap between physical properties of quantum systems and their computational complexity and computational power,” Moore says.

Among the questions the group will discuss is the so-called “area law” and whether it applies in the quantum world. In the classical realm, black holes have an area law: Incredibly, the amount of information contained in a black hole depends only on its surface area, not on its volume. The hope is that there is an area law for quantum entanglement, the extent to which the state of one quantum system can depend on another, even when separated – something Einstein called “spooky action at a distance.” If a quantum area law holds, theorists could use it to prove that the practical methods physicists use to study quantum materials are accurate.

Most of all, Moore is looking forward to learning a lot. “We’re going to ask a number of people to give, in essence, a short course on the state of the art. The working group format is perfect for that – getting experts in the room and peppering them with questions until we understand what the roadblocks are and how we can make further progress.” ■

### > Technological evolution continued from page 1

assemble economists, biologists, physicists, engineers, archaeologists, and anthropologists for talks and discussions about ways to quantify, analyze, and model technological development.

One approach posits an economy as a trophic structure, where goods flow as energy does in an ecosystem. “The flow of goods has a direction, and we can organize it accordingly,” says Farmer. “You can think of an economy as having a trophic flow precisely analogous to food webs in ecosystems. Raw materials play the same role as basal species, and final goods are like top predators. Improvements are amplified as one goes up the economic food chain, so that sophisticated final goods like computers drop in price more quickly than raw materials.”

Farmer and Oxford colleagues James McNerney (a former graduate fellow at SFI) and Francesco Caravelli believe this might at least partially explain why photovoltaic solar energy has dropped in price by a factor of more than 3,000 since 1957 while the contribution of coal to the cost of electricity has remained roughly constant for the last 150 years, with no clear trends and varying by less than a factor of five.

The invitation-only workshop, “Getting Inside the Black Box: Technological Evolution and Economic Growth,” runs August 7-30 and is funded by the Institute for New Economic Thinking, the U.S. Department of Energy, and SFI. ■





In *Does Everyone Want Democracy? Insights from Mongolia* (Left Coast Press, April 2013), SFI Professor Paula Sabloff challenges conventional wisdom about who wants democracy and why. Arguing that certain universal human aspirations exist, she shows that local realities are highly particular and explains that culture, history, and values are critical to the study of political systems. Her study of Mongolia – now struggling with post-socialist democratization – is a model for investigating how everyday people around the world actually think about and implement democracy on their own terms.



**Video: Psychologist, philosopher, author, and mother Alison Gopnik** offers insights from psychology, neuroscience, and philosophy on the development of children’s minds. Source: SFI Community Lecture video



**Video: SFI Distinguished Professor Geoffrey West** is among experts discussing innovation, cooperation, and sustainable growth. Source: Skoll Foundation “Dare to Imagine” video



**Video: Neuroscientist David Eagleman** explains that most behaviors are driven by brain networks that we do not consciously control, then asks what the implications are for the criminal justice system. Source: SFI Community Lecture video



**Video: Cardiologist and author Barbara Natterson-Horowitz** draws on the latest from medicine and veterinary science to propose an interdisciplinary approach to physical and behavioral health for doctors treating patients of all species. Source: SFI Community Lecture video



**Video: Stanford physicist Leonard Susskind** takes on the paradox of time’s arrow and offers a compelling picture of what modern cosmology says (and doesn’t say) about the directionality of time. Source: SFI Community Lecture video



**Video: Winning contestants in the first Math-O-Vision Contest** offer math-themed movies of four minutes or less in length. Source: Dartmouth College Math-O-Vision contest site

RESEARCH NEWS

Working group: How the brain handles big data

These days the term “big data” evokes thoughts of very large datasets. But in the case of an August SFI working group, “Big Data In the Brain,” the focus is the brain and how it manages large amounts of data – plus the mapping of the brain itself, which is another kind of big data challenge.

“Basically, everything in the brain involves doing calculations on large amounts of data,” says neurobiologist and SFI External Professor Charles Stevens of the Salk Institute, the meeting’s host.

There are two classes of such calculations: Those hard-wired by evolution and those that have to be learned. Hard-wired calculations, for example, are those involved in making sense of visual data from the eyes.

On the other hand, olfactory

data from the nose is more complex than building a picture in three dimensions and can’t be hardwired, Stevens explains. There are so many odors and combinations of odors that instead of three visual dimen-

sions to make sense of, olfactory perception has to juggle something like a thousand dimensions to identify a single point.

“That’s big data,” Stevens says. “So, for example, until a few hundred years ago nobody had smelled coffee. Today everybody can tell the odor of coffee, good from bad coffee, and even whether it’s from Starbucks. Evolution could not have wired it in.”

The working group’s participants – Stevens, Venkatesh Murthy of Harvard, and Stephen Smith of Stanford – also plan to discuss mapping of the brain, cell by cell, which poses a different problem: How do you handle the massive amount of data that would then describe a brain? ■



EDUCATION NEWS

Q&A with Melanie Mitchell: One MOOC down, more to go

In early 2013, SFI External Professor Melanie Mitchell taught the Institute’s first Massive Open Online Course (MOOC). The 16-week course, “Introduction to Complexity,” drew nearly 7,000 students. It marked the debut of a series of free courses and resources for complexity science SFI is providing through the online Complexity Explorer.

**Update:** This spring semester you taught SFI’s first MOOC. What kind of student were you envisioning when you first proposed the course?

**Melanie Mitchell:** The person I was mostly targeting with the lectures was anybody who had heard about complex systems, who thought it was interesting but didn’t know too

much about it, and was interested to find out what it was all about.

There were graduate students in various sciences and social sciences. There were high school students, retirees, faculty from universities, physicians, managers – you name it. And these were people from all over the world. We had maybe 100 countries represented.

**Update:** How does the MOOC fit in with the Complexity Explorer project?

**Mitchell:** Complexity Explorer is a more general website for collecting resources for complexity science education, and MOOCs are a subset of it. Right now they’re the main things that are going on with that project, but by the end of the summer we plan to have a lot more.

Complexity Explorer will have a library of simulations that people can play with, along with curricula that include write-ups about the simulation topic and exercises for students. So, for example, if you were a teacher and you wanted to teach your students about fractals, you could take some of our fractal units, which include NetLogo simulations and write-ups, and you could use them in your class.

**Update:** Do you think this MOOC can change the way people see their world on a day-to-day basis?

**Mitchell:** I think so. One of the lessons of complex systems is that interactions matter as much as, if not more than, the entities themselves. A lot of things we talk about in the course, including social networks, genetics, and so on, are really based on interactions that cause new kinds of phenomena to happen. You wouldn’t understand by just looking at the entities themselves, and I think that mindset is new for some

people. Also, the mindset that complex behaviors can come about without a sort of central controller directing them – they arise just out of the interactions of individuals. People can see that happening in their lives.

The topics are intrinsically interesting. Such topics are also coming up more and more in thinking about issues like climate change, which involves dynamics to a big degree. Thinking about modeling and simulation and how they fit into policy and decisions made by government is important for people given the problems we face in our world.

**Update:** What does the future hold for SFI MOOCs?

**Mitchell:** I’m going to be re-doing the same course in the fall with more or less the same topics. We have another course lined up for January called “Dynamics and Chaos” that’s going to be taught by Dave Feldman from College of the Atlantic.

I’m hoping that in the future we’ll be offering more such classes, that there will be a path for people to go from beginning to more advanced through this program, and that we may eventually partner with other institutions to offer for-credit options. Right now we’re sort of feeling out the territory, and our SFI program is filling a particular niche that isn’t being filled by other MOOCs.

For more information, visit [www.complexityexplorer.org](http://www.complexityexplorer.org). Development of the Complexity Explorer is supported by an SFI grant from the John Templeton Foundation. ■

ACHIEVEMENTS



SFI Science Board member Stephanie Forrest has been named one of 13 Jefferson Science Fellows for 2013-2014. She will spend a year in Washington, D.C. beginning in August as a science advisor with the U.S. State

Department and U.S. Agency for International Development (USAID). The fellowship, administered by the National Academies, is designed to further build capacity for science, technology, and engineering expertise within the State Department and USAID.



SFI External Professor and Science Board member Marcus Feldman has been elected to the National Academy of Sciences. He is among 84 new members and 21 new foreign associates. Academy membership

recognizes scientists for their distinguished and continuing achievements in original research.



SFI Trustee Cormac McCarthy was inducted into the American Philosophical Society at its meeting in Philadelphia in April. The Society’s membership of just over 1,000 includes top scholars from a variety of academic disciplines.



A UC Davis graduate course taught by SFI External Professor Jim Crutchfield, “Natural Computation and Self-Organization,” has won the 2013 Society for Industrial and Applied Mathematics Teaching Dynamical Systems Contest. The award recognizes the course’s intellectual contributions to teaching, as well as its novelty and appeal in the classroom.



Two complex systems research programs at UC Davis’s Complexity Sciences Center (<http://csc.ucdavis.edu>) led by SFI External Professors have been awarded major five-year grants by the

Department of Defense’s Multidisciplinary University Research Initiatives (MURI) program: Jim Crutchfield’s “Information Engines: Nanoscale Control, Computing, and Communication Out of Equilibrium,” a collaboration among UC Davis, UC Berkeley, the University of Maryland, and Columbia University; and Raissa D’Souza’s “Predicting and Controlling Systems of Interdependent Networks: Exploiting Interdependence for Control,” a collaboration among UC Davis, Rice University, University of Wisconsin, and Caltech. Crutchfield and SFI External Professors David Krakauer and Jessica Flack are co-investigators on the latter project. ■







CSSS



Graduate Workshop

The four-week 2013 **Complex Systems Summer School**, held annually in Santa Fe and at various times in China and South America, was the 32th SFI summer school in 25 years. The 2013 school's 59 participants included an interesting first: a 2nd generation SFler.

"My father was a postdoc at SFI for a short time while I was a baby, so I've been there before," says 2013 CSSS student Oskar Lindgren, a PhD candidate at Chalmers University of Technology, Sweden. "The reason I came was that both my father, my supervisor, and another colleague have been and enjoyed their stays immensely. CSSS is supposed to be unique and an opportunity not to be missed. I can see how that is true now."

The program introduces graduate students and postdocs to a range of topics in complex systems science. This year's program

ran June 3-28, directed by SFI External Professor Sander Bais.

Several of this year's lecturers were past CSSS participants.

SFI External Professor Aaron Clauset spoke to this year's CSSS class about networks, human social dynamics, and competition. "Returning 10 years after I was a student was a special experience for me," he says. "I enjoyed chatting with the students about their projects and ideas, and I was impressed with the thoughtfulness of the questions they asked during my lectures. It was great fun to be back, and I hope some of these students can stand on the stage as lecturers in a few years to give back to the next generation, as I was able to this time."

SFI Postdoctoral Fellow Clio Andris, a member of SFI's Cities & Urbanization research team, lectured on networks and cities.



# SFI's 2013 summer education programs

*This year's programs feature returning lecturers, and one 2nd generation SFler*



Graduate Workshop



CSSS



Graduate Workshop



CSSS



REU





CSSS



Graduate Workshop



CSSS

“When I was a summer school student, I looked up to the postdocs at SFI so much, and I never thought I would get to be a part of their group. Getting to talk with them after class, or when they came out at night, was a nerdy little ‘hollywood’ for me.”

“I was especially proud of this year’s students for coming to the school not as a physicist or as a biologist, but as someone who wanted to learn interdisciplinary concepts and learn from each other,” she adds. “[This] reminded me that the best thing to come to CSSS with is an open mind.”

SFI’s **Graduate Workshop in Computational Social Science, Modeling, and Complexity** offers a small group of grad students from economics and the social sciences a chance to design their own projects and use computational techniques to answer social dynamics questions. The 2013 workshop’s co-directors were SFI External

Professors Scott Page and John Miller.

Miller says this year’s 10 participants were among the most diverse in the program’s 19 years, with scholars from sociology, economics, international and public affairs, political science, management, and marketing.

“For two weeks each summer we have the opportunity to form the most interesting social science department in the world,” he says. “We gather together this incredibly bright, creative, and motivated group and encourage them to pursue the big questions in interesting ways. There’s this immediate fellowship that forms among the group, as students put in long hours in the pursuit of new ideas. Former students often report that this is one of the most meaningful experiences they had in graduate school, which I take as both a sign of what we are doing right and of what graduate education is doing wrong.”

This year’s Graduate Workshop took place June 16-29 in Santa Fe.

SFI’s **Research Experiences for Undergraduates** pairs undergraduate scientists with SFI faculty mentors. Participants are encouraged to investigate complex social systems through a research project they design with their mentors.

SFI VP for Education and Outreach Ginger Richardson says the program’s goals include sending young scholars back to their home institutions with new methods, big ideas, and confidence to tackle complex systems problems.

“The training extends to the entire research process, from conception to completion: how to focus big, ambitious questions down to a manageable size, how to work with data, how to build results and statistical tests into an effective argument, how

to prepare a research presentation, how to write a scientific paper and navigate the peer-review process,” says REU Robert Hawkins. “When this summer is over, I’ll take away a strong foundation for a career in research and a set of lasting friendships.”

The 2013 REU program runs June 3-August 9 in Santa Fe. Thirteen undergraduates are participating, including a small cohort of “advanced” participants – returning program alumni who serve as mentors and continue their research.

“Most of my research experience so far had been on fairly traditional computer science topics, and I wanted to branch out to areas that truly interested me but that I hadn’t had a chance to work with,” says 2nd year REU Bryan Wilder. “It’s been incredibly valuable to interact with researchers across such a wide range of disciplines and institutions, and I can’t think where else I’d have that chance.” ■



CSSS



REU



CSSS



Graduate Workshop



# Crowd wisdom economics: The bad news about bad institutions

Volkswagen is simply a better car company than Fiat. Profits are higher, and so are wages. Why doesn't Fiat just be like VW? Why doesn't Italy, for that matter, emulate Germany?

Is it elites that perpetuate lousy economic institutions and unhelpful social norms? Or is it the weight of tradition?

Maybe none of the above: Even the most rational people often persist in perpetuating a status quo that leaves everyone worse off. That's the message of a new paper published in the *American Economic Review* by Marianna Belloc (Sapienza University, Rome) and SFI Professor Sam Bowles.

The researchers show that groups of people can get stuck in a bad situation because nobody has an incentive to make a change unless most of the others also make the move. At Volkswagen, managers share decision making with workers and workers work cooperatively, to everyone's benefit. At Fiat, managers make all the decisions, and workers take an aggressive stance toward their managers.

"As long as managers at Fiat act like control freaks, workers have no incentive to cooperate," Bowles explains, "and as long as workers are ready to hit the barricades at the drop of a hat, managers have little incentive to give them a seat at the table."

Belloc and Bowles provide a math-  
[> more on page 8](#)

Workers from the Redbank meatworks lined up at the factory, circa 1900 (Image: Wikicommons via John Oxley Library, State Library of Queensland)



## SFI SCIENCE BRIEFS



### Ice Age ancestors might have used some of our words

New research by SFI External Professor Mark Pagel and collaborators at Reading University shows that Ice Age people living in Europe 15,000 years ago might have used forms of common words that in some cases could still be recognized today. Their paper appeared May 6 in *PNAS*.

Previously, linguists have relied solely on studying shared sounds among words to identify those that are likely to be derived from common ancestral words. But what if two words share sounds just by accident? Using statistical models, the Reading researchers predicted that certain words used frequently in everyday speech are more likely to have changed so slowly over long periods of time as to retain traces of their ancestry for 10,000 years or more. The team used this method to predict words likely to have shared sounds, giving greater confidence that when such sound similarities are discovered they reflect more than the workings of chance.

The findings point to the existence of a linguistic super-family tree that unites seven major language families of Eurasia: Indo-European, Uralic, Altaic, Kartvelian, Dravidian, Chukchee-Kamchatkan, and Eskimo-Aleut.

### How temperatures would alter species interactions

A recent paper in the *Journal of Animal Ecology* by SFI External Professor Van Savage and UCLA collaborators examines how various traits of organisms might respond to changes in their environments. In particular, using their "biotraits database" and new species interaction models, the researchers have shown how changes in metabolism due to warmer temperatures affect the rates at which organisms eat, move, and sleep, and they have made predictions about how changes in those activities would affect the broader ecology.

"Models that assume all species respond to temperature in the same way will both miss the large diversity in ecological systems and the most important consequences that arise from differential and asymmetric responses to temperature among species," Savage says.

### Interlock device study shows fewer crashes since 2005

Four Santa Fe-area high school students teamed up with SFI Omidyar Fellows James O'Dwyer, Charles Perreault, and Paul Hooper to study the effectiveness of ignition interlock devices in curbing drunk driving accidents in New Mexico.

As part of a mentored project, the students – high school seniors Arlo Barnes, Krishan Bhakta, and Noah Kwicklis, and junior Raj Singh – chose a statistical analysis of the effectiveness of New Mexico's 2005 ignition interlock law, which mandates that drivers install interlock devices after the first drunken driving offense. They compared data from New Mexico with nine other states, statistically isolating the effects of interlock devices from other variables. Their study estimates that New Mexico's law has resulted in 700 fewer alcohol-related crashes and 27 fewer fatal car crashes since 2005.

### Famine in early life linked to diabetes in later life

People born during three major 20th century famines in Austria were more likely to develop diabetes later in life than those not born during famines, according to a study by SFI External Professor Stefan Thurner and collaborators, published in *PNAS* on March 4.

The researchers studied the diabetes rates for nearly 8 million Austrian patients born each year from 1917 to 2007. Depending on the region, they found a significantly greater chance of patients being treated for diabetes later in life when they were born during one of three famines in Austria compared to those born in surrounding years or in provinces less affected by famines. The results underscore the importance of proper prenatal and youth nutrition, the researchers say. ■

## RESEARCH NEWS

# Which came first: private property or farming? Wrong question, says paper

It has long been assumed that the advent of farming some 12,000 years ago led to the birth of private property rights. But new data on the productivity of early farming and hunting-gathering lifestyles, along with new mathematical modeling by SFI researchers, tell a very different story.

In a May 13 paper in *PNAS*, SFI Professor Sam Bowles and Jung-Kyoo Choi of Kyungpook National University show that farming and private property rights evolved shoulder-to-shoulder, each dependent on the other.

"Our results challenge the one-cause models in which history is driven by advances in technology, population pressure, or other external changes," says Bowles. "We show how farming and private property rights each provided conditions favorable for the proliferation of the other. We propose that the new property rights and the new way of making a living co-evolved, neither being viable alone but each providing the conditions

permitting the advance of the other."

Explaining how farming took hold is a long-standing puzzle. The first farmers were no more productive or well-fed than the hunter-gatherers they replaced, and they would have needed to make large investments in clearing land, planting seeds, sowing crops, storing food, and tending domesticated animals – investments for which the eventual rewards were far from certain.

But farming did succeed, and the researchers' new modeling shows that it did so because the wealth of farmers – crops, dwellings, and animals – could be clearly demarcated and defended; that is, it could be turned into private rather than communal property.

"In the Bowles/Choi model, ecological, economic and social facets come together as a co-evolutionary development," says Bruce Winterhalter, a professor of anthropology at UC Davis. ■

## RESEARCH NEWS

# Early Clovis knew their land and stone

Some 60 km southeast of Socorro, N.M., a low gravel ridge runs above the Chupadera Wash in the Rio Grande Rift Valley. The remote Mockingbird Gap is a dry, narrow strip half a mile long, but thousands of years ago it was a lush wetland – and a popular site for an early Clovis culture, judging by the wealth of projectile points found there.

Recently, anthropologist Marcus Hamilton, a postdoctoral fellow at SFI and the University of New Mexico, and colleagues examined 296 projectile points from two locations: Mockingbird Gap and a region in the central Rio Grande Rift collected by the late geologist Robert Weber over 60 years ago, the earliest and biggest collection of Clovis tools yet found.

The broad, bifacial spear points fit the manufacturing pattern the Clovis used 13,000 years ago. Geological analyses link all the points' obsidian, chert, and other high-quality stone to a handful of rock outcrops, mostly nearby but some hundreds of kilometers away.

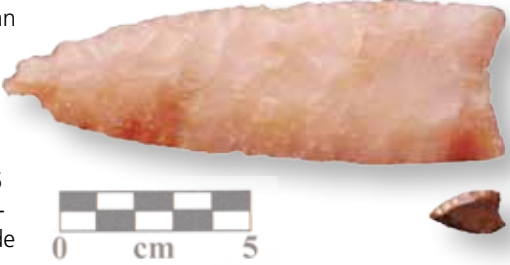
"The two assemblages are probably linked, as all the raw materials are coming from known outcrops in the northwest corner of New Mexico," Hamilton says. "It suggests strongly that the same people probably settled in this region for a while."

The clusters of artifacts suggest different camping events, possibly by groups coming together, briefly, over many years, to camp seasonally amid a verdant Pleistocene riverside.

Hamilton's research interests include understanding how human ecology evolved, partic-

ularly its shift from hunter-gatherer lifestyles to more settled agrarian societies.

The study of Clovis points "gives you a nice flavor of what



human adaptation and human ecology looked like at the time, where Mockingbird Gap was a summer camp," he says.

One distant source of obsidian, Cow Canyon, is so small that residents "would have to know it, not stumble across it," he says. A novel find was a set of miniature points, just a few millimeters long, that might have been children's toys or pieces flintknappers practiced on while learning point-making techniques.

The rich findings in this poorly documented region indicate that early human arrivals to North America adapted to the landscape in part by learning a vast geographic region in great detail, the paper notes.

The researchers reported their findings in a study in the April 2013 issue of *American Antiquity*. Hamilton is a contributor to SFI's "Emergence of Complex Societies" project. ■



# Recent appointments to boards, faculty



Former U.S. Senator Jeff Bingaman was elected to SFI's Board of Trustees during the Institute's 2013 Science Board Symposium and Meeting in early May. His three-year appointment began May 5, 2013.

Bingaman is a former United States Senator from New Mexico, serving in the Senate from 1983 to 2013. Previously, he was Attorney General of New Mexico from 1979 to 1983. He is a fellow of the Stanford Law School Steyer-Taylor Center for Energy Policy and Finance.

## Science Board appointments

Six new members were appointed to SFI's Science Board. Their three-year appointments began July 1, 2013.

- Barbara Grosz, Harvard University, artificial intelligence collaborative planning and human-computer communication
- Kevin Laland, St. Andrews University, social learning, inheritance of behavior, and evolution of intelligence
- Michael Mitzenmacher, Harvard University,

computer science, heuristics, and information theory

- SFI External Professor Mercedes Pascual, University of Michigan, ecology and evolutionary biology
- SFI External Professor Mark Pagel, University of Reading, language and cultural evolution, statistical modeling of evolutionary processes
- SFI External Professor Andreas Wagner, University of Zurich, evolution of biological systems

## External faculty appointments

Four people were named SFI External Professors. Their three-year appointments began July 1, 2013.

- Miguel Fuentes, Research Center for Social Complexity, Santiago, Chile, modeling of social complexity
- Sabre Kais, Purdue University, electronic structure of finite systems, quantum information and quantum computing
- Ole Peters, London Mathematical Laboratory, stochastic processes in complex systems
- Charles Stanish, UCLA, Andean anthropology, settlement archaeology, and the evolution of social complexity ■

## > Great exaptations continued from page 1

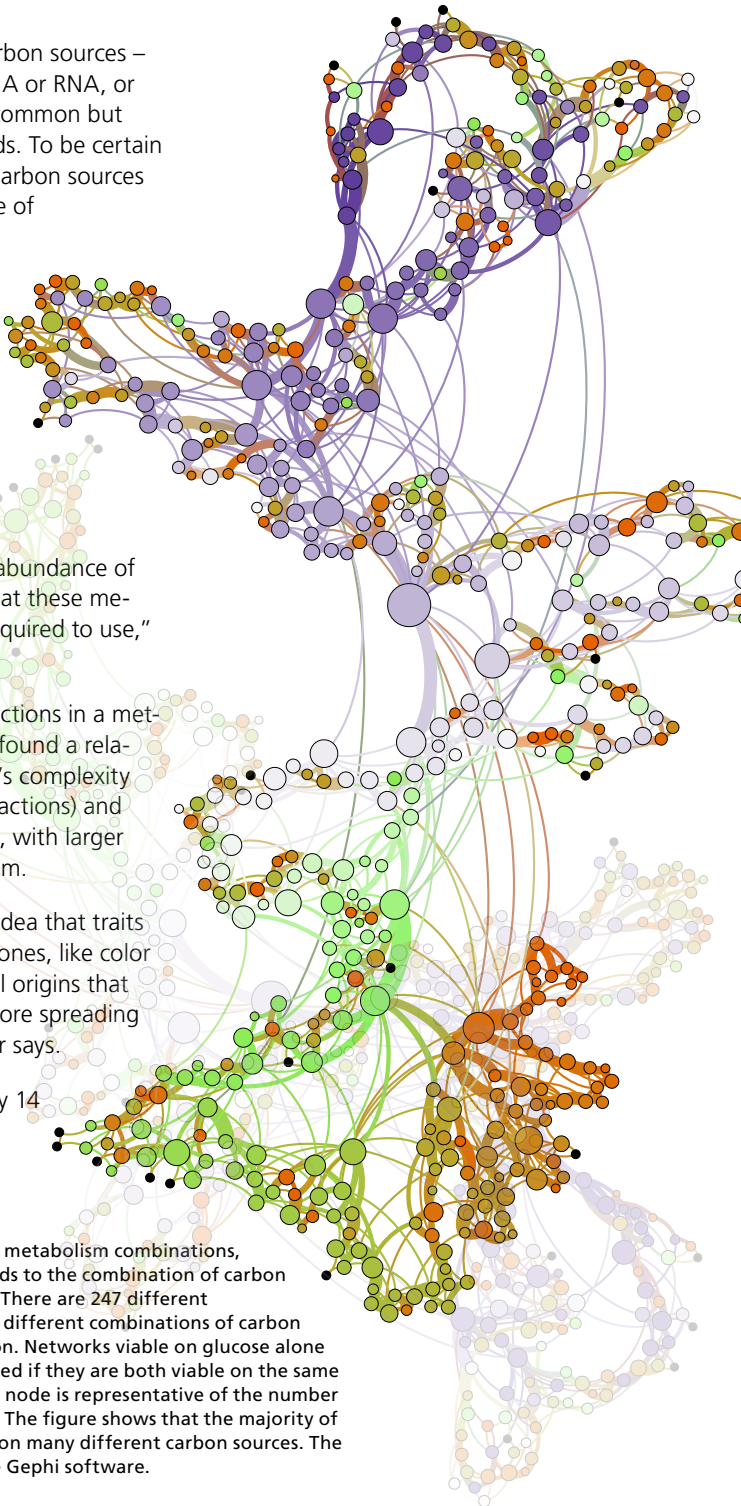
viable on about five other carbon sources – sugars, building blocks of DNA or RNA, or proteins – that are naturally common but chemically distinct compounds. To be certain that viability on these other carbon sources wasn't a natural consequence of viability on glucose, they tested metabolisms starting with viability on 49 other carbon sources, and each time found that exaptations emerged allowing the metabolism to survive on any one of several other carbon sources alone.

"We observed an incredible abundance of viability on carbon sources that these metabolisms were never even required to use," Wagner says.

By varying the number of reactions in a metabolic system, the team also found a relationship between the system's complexity (determined by number of reactions) and the extent of the exaptations, with larger networks having more of them.

The findings underscore the idea that traits we see now – even complex ones, like color vision – may have had neutral origins that sat latent for generations before spreading through populations, Wagner says.

Their work was published July 14 in the online edition of *Nature*. ■



In this network diagram of *E. coli* metabolism combinations, the color of each node corresponds to the combination of carbon sources the network is viable on. There are 247 different phenotypes in this graph, that is, different combinations of carbon sources the networks are viable on. Networks viable on glucose alone are black. Two nodes are connected if they are both viable on the same carbon source, while the size of a node is representative of the number of other nodes it is connected to. The figure shows that the majority of networks (96 percent) are viable on many different carbon sources. The figures were generated using the Gephi software.

## > Cities continued from page 1



about urban policies that create positive social interactions at low costs in terms of mobility and energy use, for example. The paper shows how obstacles to socialization, such as crime or segregation, and enablers that promote the ability of people to connect, such as transportation and electricity, all become part of the same equation.

It even names a couple of U.S. cities that appear to be sub-optimal in terms of their social interactivity. Brownsville, Tex., and Riverside, Calif., for example, might benefit from policies to

improve citywide connectivity. Bridgeport, Conn., which includes Connecticut's "Gold Coast," could be a victim of its own socio-economic success, as high mobility costs suggest that more compact urban living or more efficient transportation might be in order.

So what is a city? Bettencourt thinks the only metaphor that comes close to capturing a city's function is from stellar physics: "A city is first and foremost a social reactor," Bettencourt explains. "It works like a star, attracting people and accelerating social interaction and social outputs in a way that is analogous to how stars compress matter and burn brighter and faster the bigger they are."

This, too, is an analogy though, because the math of cities is very different from that of stars, he says. Cities are also massive social networks, made not so much of people but more precisely of their contacts and interactions. These social interactions happen, in turn, inside other networks – social, spatial, and infrastructural – which together allow people, things, and information to meet across urban space.

Ultimately, cities achieve something very special as they grow, he says. They balance the creation of larger and denser social webs that encourage people to learn, specialize, and depend on each other in new and deeper ways with an increase in the extent and quality of infrastructure. Remarkably, they do this in such a way that the level of effort each person must make to interact within these growing networks does not need to grow.

How these networks fit together, and the tensions and tradeoffs among them, often determines how productive or prosperous a city is, or whether it fissions into smaller 'burbs, or if people want to live in them or don't, Bettencourt says.

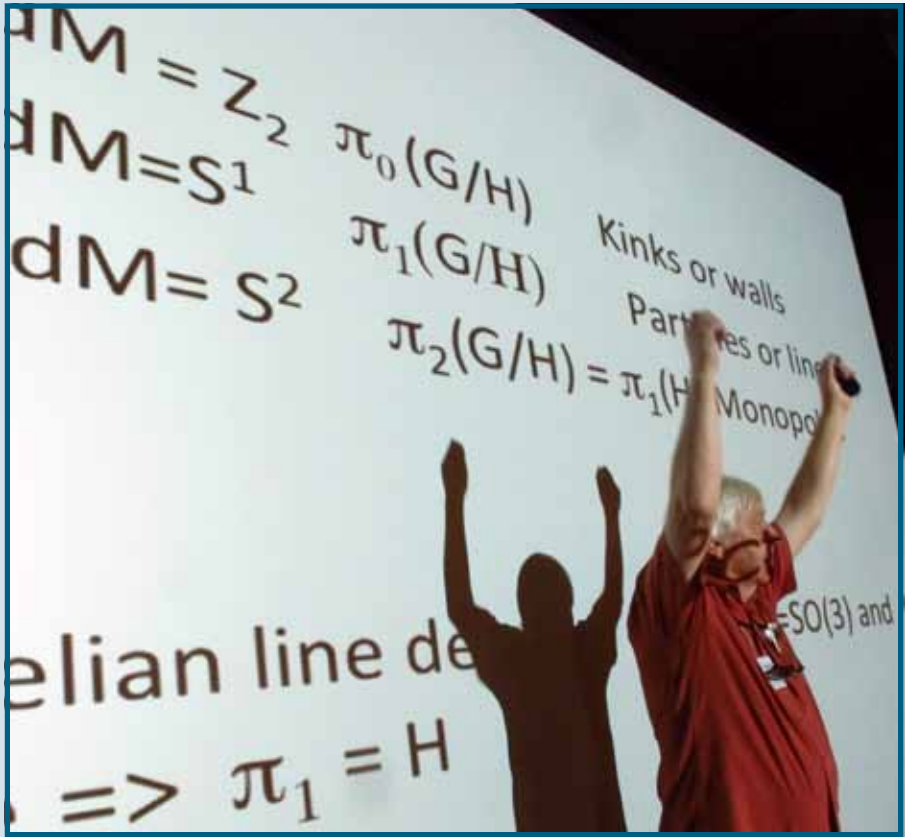
The framework has practical implications for policy makers, he says. To keep our social reactors working optimally, planners need to think

The framework is a first theoretical step, Bettencourt says, and much more needs to be done. In the coming years, better data from cities in developing nations will become available, which will provide new opportunities to test the theory in places where understanding urbanization is most critical.

"Rapid urbanization is the fastest, most intense social phenomenon that ever happened to humankind, perhaps to biology on Earth," says Bettencourt. "I think we can now start to understand in new and better ways why this is happening everywhere and ultimately what it means for our species and for our planet." ■



## June's SFI photo contest winners



2013 Complex Systems Summer School (CSSS) participant Joana Patricio took this vivid photo of 2013 CSSS Director Sander Bais; the image is June's top photo in the Institute's 2013 photo contest. Two other winning photos for June are published at the top right of page 1 of this issue: Camden German's mathy shot of a researcher working in SFI's courtyard, and Sander Bais's colorful image of J.P. Gonzales over a sand table during this year's CSSS. Each month from June through October 2013, one winning photo in each of four categories will be selected for prizes by our panel of judges, and a top submitter will win a special prize. To be eligible for each month's judging, you must upload your entries before midnight MDT on the last day of each month. Photos need not be taken during the month of entry. ■

See [www.santafe.edu/photo](http://www.santafe.edu/photo) for categories, prizes, and detailed instructions.





# Ross Buhrdorf: ‘What’s the difference that makes the difference?’



While everyone knows innovation when they see it, little is known about how innovation happens. SFI Trustee and Business Network member Ross Buhrdorf likens this to the 1996 movie *Twister*; everyone who saw it thought they understood how tornadoes form, but it took until 2003 for scientists to gather enough data to create a computer model of a tornado.

Buhrdorf, the chief technology officer of HomeAway, Inc., says people approach innovation with a similar level of understanding; they see a startup company crammed with young and ambitious people and think they must be the force that governs innovation.

He says it’s not enough to recognize innovation after it has happened; the question of how to define and cultivate it requires a scientific approach. “I’d like to understand the critical pieces in innovation,” Buhrdorf

says. “What’s the difference that makes the difference?”

Buhrdorf first came to SFI for a science symposium in 2011. He was impressed with its researchers’ practical approach to modeling the big questions in science. He soon joined the Business Network and was invited to join the Board of Trustees shortly thereafter.

As a Business Network member, Buhrdorf recently hosted a topical meeting on innovation at his company’s headquarters in Austin, Texas. Speakers Doug Erwin (Smithsonian) and Brian Authur (Palo Alto Research Center and SFI) explored innovation from the dual perspectives of evolutionary biology and human-created technology.

“What is an F5 innovation...or an F1?” he asks, a reference to hurricane intensities. “Is Google’s search algorithm an F5 innovation? Are daily innovations F2s? SFI really tries to take us out of our Hollywood movie understanding and gets data and builds models. This is what needs to be brought to innovation.” ■

## > *Bad institutions* continued from page 6

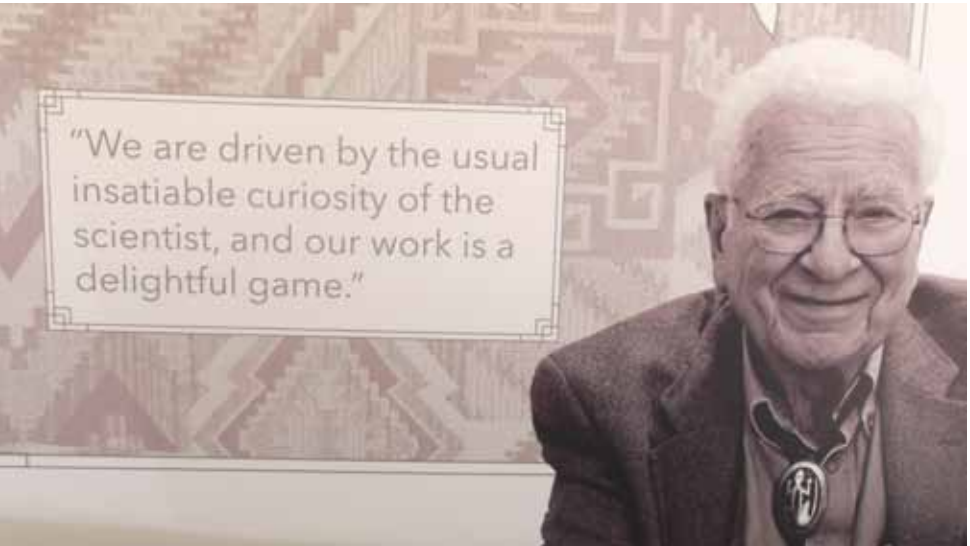
ematical model of how dysfunctional institutions and cultures can persist indefinitely in these vicious cycles. Their work is part of SFI’s ongoing research on the co-evolution of institutions and behaviors, the topic of a regular series of SFI working groups.

Change for the better can happen, the researchers show, when enough people simply refuse to conform to the status quo. But those who do this lose economically by stepping out. Think Rosa Parks. And unless

the deviants get together, it can be a long wait until this happens, and longer still the more intent people are on maximizing their own gains.

And there’s news for those who believe a rising tide lifts all boats: Trade liberalization will slow the transition to a better situation. “Even in a lousy status quo, the economic gains from trade liberalization mean that it makes less sense to risk losing out by swimming against the current,” explains Belloc. ■

# Santa Fe Children’s Museum unveils SFI-inspired cities exhibit



SFI Distinguished Professor Murray Gell-Mann and a quote attributed to him are featured prominently in the new Thinking Lounge in the Museum’s solarium, along with other famous scientists.

A new multimedia exhibit at the Santa Fe Children’s Museum gives kids a glimpse of what SFI scientists are learning about cities.

SFI Professor Luis Bettencourt and Post-doctoral Fellow Clio Andris worked with Museum staff and Media Arts students at New Mexico Highlands University to develop materials for the hands-on interactive exhibit, designed to help children understand the complex physical and social systems that comprise a city.

The researchers wanted to convey that cities are complex systems of people and interactions rather than just collections of buildings.

A six-panel interactive wall piece titled “What Makes a City?” guides children through questions about how a city functions using photographs, data visualization, touch-and-feel components, time-lapsed video, and more. A Lego building area encourages young visitors to build their own cities.

A Thinking Lounge in the museum’s solarium features oversized photos and inspirational quotes from scientists, including an Albert Einstein quote in large letters that captures the spirit of the exhibit: “Play is the highest form of research.”

Outside, nine colorful banners with photos of children from Santa Fe’s sister cities are on display.



“We rarely get our research ‘out there’ in the public space because it’s never complete – we are always thinking and revising,” says Andris. “Making it accessible to kids was a fun challenge.”

Science of Cities was made possible through funding from the Delle Foundation. The exhibit opened May 10. ■

July / August 2013

UPDATE

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## Upcoming SFI events

In a relatively brief 150 years, the human impact on natural systems has perhaps irrevocably brought us to an inflection point that we do not yet fully understand. In the coming decades, the demands on natural systems will continue on a path of increasing intensity and complexity. Meeting these new and highly complex challenges will require large-scale team efforts that link academia, industry, and governments.

In a July 31 SFI Community Lecture titled “New Problems, New Partnerships: What Tomorrow’s University Must Be,” Michael Crow explains why conventional interdisciplinary approaches might not be sufficient to address tomorrow’s challenges. He then suggests an academic enterprise that adapts to emerging complexities and enhances our ability to manage tomorrow’s challenges.

Crow is President of Arizona State University. Since 2002 he has guided the transformation of ASU into one of the nation’s leading public metropolitan research universities – a model he terms the “New American University.”

The lecture begins at 7:30 p.m. and takes place at the James A. Little Theater in Santa Fe.

### Future SFI Community Lectures

**Wednesday, August 14, 7:30 p.m., On Moral Progress: Reason and Logic or Empathy and Emotion.** Psychologist and author Steven Pinker and philosopher and novelist Rebecca Newberger Goldstein survey the history of moral progress in human society.

**Tuesday, Wednesday, & Thursday, September 10-12, 7:30 p.m. each night, 2013 Stanislaw Ulam Memorial Lectures: Complexity and the Biology of Computation.** SFI External Professor and Science Board member Stephanie Forrest, a professor of computer science at the University of New Mexico, takes on three critical topics in our hyper-connected world – Cybersecurity: Computer Immune Systems (September 10); Software Engineering: Evolving Computer Programs (September 11); and Modeling the Internet: Ecology and Policy (September 12).

SFI’s 2013 Community Lectures are made possible through the generous support of Los Alamos National Bank. Lectures are free and open to the public, but seating is limited. Visit [www.santafe.edu](http://www.santafe.edu) for more about SFI’s 2013 lecture series.

NEW: Lectures are now broadcast live online. To watch a lecture as it happens, visit SFI’s YouTube page. Participate in the discussion live on Twitter at @sfi\_live or #sfi\_live. ■

