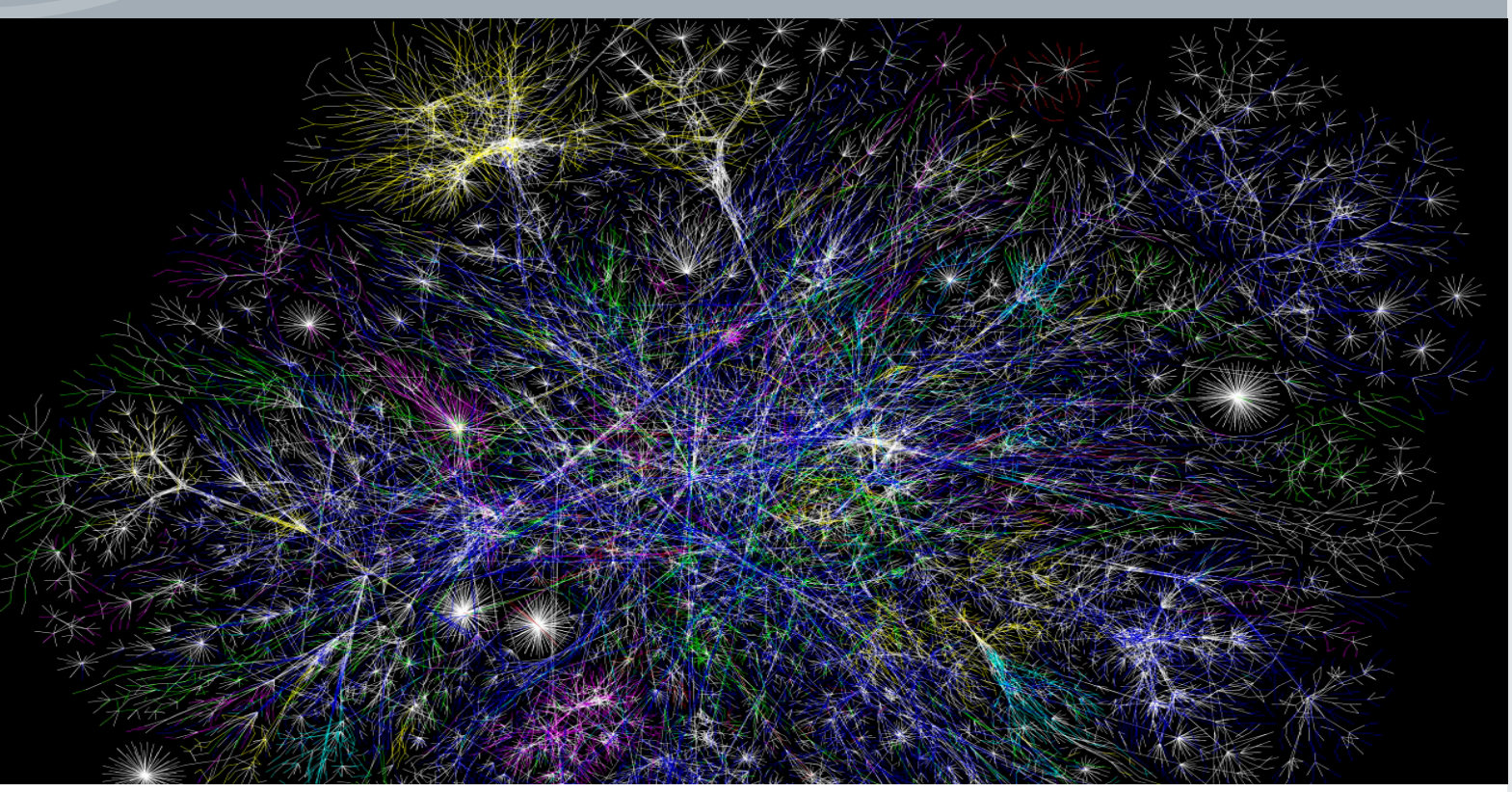
SANTA FE INSTITUTE

January / February 2016

UPDATE



Partial map of the Internet. Nodes represent IP addresses. Edge (line) lengths indicate delay duration between two nodes. Node colors: dark blue .net, .ca, .us; green .com, .org; red .mil, .gov, .edu; yellow .jp, .cn, .tw, .au, .de; magenta .uk, .it, .pl, .fr; gold .br, .kr, .nl; white unknown. (Image: Matt Britt, Wikimedia Commons)

Workshop: An overdue overhaul for network theory

Networks are everywhere – from social interactions to species feeding relationships to the algorithms that pull information from large datasets. Because of its broad utility in quantifying interacting systems, network theory now finds application in many disciplines. But network science, like any emerging field, needs to keep up with the times.

A network is traditionally regarded as a static array of nodes connected by links, but an overhaul of that view is long overdue, says SFI Professor Cristopher Moore.

"Many of the models we've had in the past are too simple," says Moore, who dwells at the intersection of physics, mathematics, and computer science. "They don't capture the rich structure of real networks like power grids or food webs."

Networks should be approached not as static objects, but as dynamic systems that change in time, he says. Similarly, nodes and edges aren't flat and anonymous – they often have rich metadata, like location for nodes or duration for edges, that should be incorporated into new models.

Moving beyond the antiquated view of networks was one goal of a mid-December SFI workshop, Inference on Networks: Algorithms, Phase Transitions, New Models, and New Data. Moore co-organized the meeting with computer scientist Aaron Clauset (University of Colorado Boulder) and physicist Mark Newman (University of Michigan), both SFI external professors.

The workshop's second goal, Moore says, was to assemble researchers from disparate fields to forge novel insights. The last decade, he says, brought an "exciting flow of ideas" among physicists, mathematicians, and computer scientists who create algo-

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RESEARCH NEWS

Semantically speaking: Does meaning structure unite languages?

We create words to label people, places, actions, thoughts, and more so we can express ourselves meaningfully to others. Do our shared cognitive abilities and dependence on languages naturally provide a universal means of organizing certain concepts? Or do environment and culture influence each language uniquely?

Using a new methodology that measures how closely words' meanings are related within and between languages, an international team of researchers has revealed that for many universal concepts, the world's languages feature a common structure of semantic relatedness.

"Before this work, little was known about how to measure [a culture's sense of] the semantic nearness between concepts," says co-author and SFI Professor Tanmoy Bhattacharya. "For example, are the concepts of sun and moon close to each other, as they are both bright blobs in the sky? How about sand and sea, as they occur close by? Which of these pairs is the closer? How do we know?"

Translation, the mapping of relative word meanings across languages, would provide clues. But examining the problem with scientific rigor called for an empirical means to denote the degree of semantic relatedness between concepts.

To get reliable answers, Bhattacharya needed to fully quantify a comparative method that is commonly used to infer linguistic history qualitatively. (He and collaborators had previously developed this quantitative method to study changes in sounds of words as languages evolve.)

"Translation uncovers a disagreement between two languages on how concepts are grouped under a single word," says co-author and SFI researcher Hyejin Youn. "Spanish, for example, groups 'fire' and 'passion' under 'incendio,' whereas Swahili groups 'fire' with 'anger' (but not 'passion')."

To quantify the problem, the researchers chose a few basic concepts that we see in nature (sun, moon, mountain, fire, and so on). Each concept was translated from

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IN THIS ISSUE

RESEARCH NEWS

Mapping the movements of birds and beasts

Be they creatures of land, sea, or air, most animal species migrate. Whales, salmon, songbirds, and butterflies, for example, all travel thousands of kilometers to and from breeding and feeding grounds every year.

Theory and lab experiments suggest migrating *en masse* can help animals find their way. Creatures traveling together are thought to pool the many directional estimates of the members of a group, in essence tapping into the "wisdom of the crowd."

So goes the hypothesis, anyway. Testing it is not easy. The challenge of actually tracing the individual trajectories of group-traveling animals in the wild has kept the available data sparse.

"Technology is about to change this," explains SFI Omidyar Fellow Andrew Berdahl. He has been awarded a National Science Foundation grant to use airborne drones to study a caribou herd as it travels from its summer territory on Victoria Island above the Arctic Circle to its winter grounds on mainland Canada.

The Dolphin-Union herd, a migratory population of barren-ground caribou in northern Canada, "is an excellent test case for collective navigation because they face a unique navigational challenge annually as they traverse treacherous ice bridges," says Berdahl, referring to autumn, when the herd congregates on shore and ventures out on newly frozen ice to cross the 30-plus-kilometer-wide Dolphin and Union Strait.

"The idea is to use unmanned aerial vehicles – drones – to film animals from above, then use computer vision software to track individuals," he says. Once he has the trajectory of each animal in a group, he can work out interaction rules between individuals and

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The *Wall Street Journal* on December 11, in an interactive piece on sustainability and urbanization, highlighted SFI's finding that human interaction and innovation seem to accelerate as a city's population grows.

SFI's year-long complexity series in the *CS Monitor* launched November 3 with "Complexity: Worlds hidden in plain sight," by SFI President David Krakauer. His introductory essay was followed by "A planet of cities" by SFI Professors Luis Bettencourt and Geoffrey West on November 17, "Time for new economic models" by George Mason University's Rob Axtell and SFI External Professor Doyne Farmer on December 1, and "Are humans truly unique?" by SFI VP for Science Jennifer Dunne and Postdoctoral Fellow Marcus Hamilton on December 23.

Articles in *Quanta* and *Wired* quote SFI Omidyar Fellow Josh Grochow in articles describing an algorithm that many computational complexity theorists believe might be a major breakthrough in the historically vexing "graph isomorphism problem."

MIT Technology Review on December 14 covered a recent paper by Markus Schläpfer, Luís Bettencourt, and colleague Joey Lee that finds that city building shapes can be predicted as a function of population size, with potentially important implications for carbon emissions and sustainability.

Science magazine highlighted a proposed new approach to identifying cell types based on gene expression patterns that reveal which parts of a cell's genome are active, rather than on traditional methods of typing a cell based on its structure, function, or location within an organism. The approach was the subject of a recent working group at SFI.

A provocative November 27 radio interview on PRI's To the Best of Our Knowledge with SFI President David Krakauer explores the dangers of abdicating our free will to the almighty app.

SFI's cities and urbanization research is featured in a lengthy November 9 article in the leadership publication *Strategy+Business* that recounts the history of this research, beginning with insights in the late 1990s by SFI Professor Geoffrey West and collaborators that organisms and cities share some intriguing mathematical similarities.

A lengthy September 15 article in *Sueddeutsche Zeitung*, the largest-circulation daily newspaper in Germany, covered the August 5 event in Santa Fe featuring SFI President David Krakauer, visual artist James Drake, passages from SFI Trustee Cormac McCarthy's forthcoming novel *The Passenger*, and music by McCarthy's son John Francis McCarthy. ■

Nonlinearities

From the editor

Art and science are colliding a lot here lately. This fall we were treated to Ice Station Quellette, an exhibition of digital collages by Santa Fe artist Lauren Oliver. ISQ tells the story of a "tiny outpost on a doomed planet," narrated from the distant future but set in the past, present, and near-future Arctic Circle. From the perspective of artificial hindsight, the warning signs of planetary change are, well, glaring. A beautiful, moving work. More at http://isq.io.

In November, we hosted a unique display of currency objects, in part featuring African metal pieces collected by Santa Fe ironwork sculptor Tom Joyce. The exhibition complemented the Institute's November symposium.

Joerael Elliott, a graffiti and public-space artist who recently moved to Santa Fe from Los Angeles, can be seen in SFI's open spaces this winter interpreting the Institute's research in his own language. See an example drawing on page 4.

Irene Lee has taken a research scientist position with MIT's Scheller Teacher Education Program and Education Arcade. Under Lee's leadership, the Institute's K-12 education programs had grown so rapidly and been so successful, they took on a scale and focus that were beyond SFI's research mission. Rather than limit its scope and direction, Lee chose to move her research to MIT, where she is part of an accomplished community of innovators pursuing educational initiatives in science, technology, engineering, math, and computing. We'll miss Irene, and so will educators and young scientists across New Mexico. The good news: She plans to continue her important efforts on the national stage.

For the second consecutive year, SFI has earned the highest possible rating from the independent nonprofit evaluator Charity Navigator, certifying that SFI manages its operations and finances responsibly and transparently. Just 21 percent of evaluated charities are able to maintain this rating for two or more years. Congratulations to my SFI colleagues, especially our hard-working finance office. This achievement is not just for our trophy case. It reminds our donors and prospective supporters that we are worthy of their investment. In a world of choices, that's important. ■

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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

Designing difficult problems

The traveling salesman problem is easy to describe and hard to solve with certainty. It goes like this: A salesman – or a UPS driver, or the Tooth Fairy – must visit a number of cities and end where she or he began. What's the most efficient route? With more cities, the problem becomes vastly more complex.

Computer scientists study optimization problems like the traveling salesman not because they want solutions, but because they want to find algorithms that can do such heavy computational lifting. The ideal algorithm identifies the best strategy and proves that no others are better. Ordinary computers balk at the task, but quantum computers might do better.

Benchmark problems are needed to test new algorithms and computer architectures like quantum machines. Quantum annealers – devices that can identify the optimal solution to a problem – increase in power every year, which means testing their efficiencies will get increasingly difficult.

A common approach to difficult optimization problems is a reverse-engineering process called "planting solutions," in which researchers start with a dataset and devise a problem that describes the data.

"Imagine you measured some experimental result, and you know it could be understood with a mathematical model," says SFI External Professor Helmut Katzgraber (Texas A&M). "The question is, can you build a model out of the results that shows the underlying physics?"

Katzgraber organized a two-day working group in December, The Inverse Ising problem and Planted Solutions, to talk strategies. Invitees included experts in the inverse Ising problem, machine learning algorithms, and quantum annealing.

"These people have worked on related projects from different angles, and my hope is that by combining these angles we find something that successfully advances our understanding," he says. ■

> ***Language***
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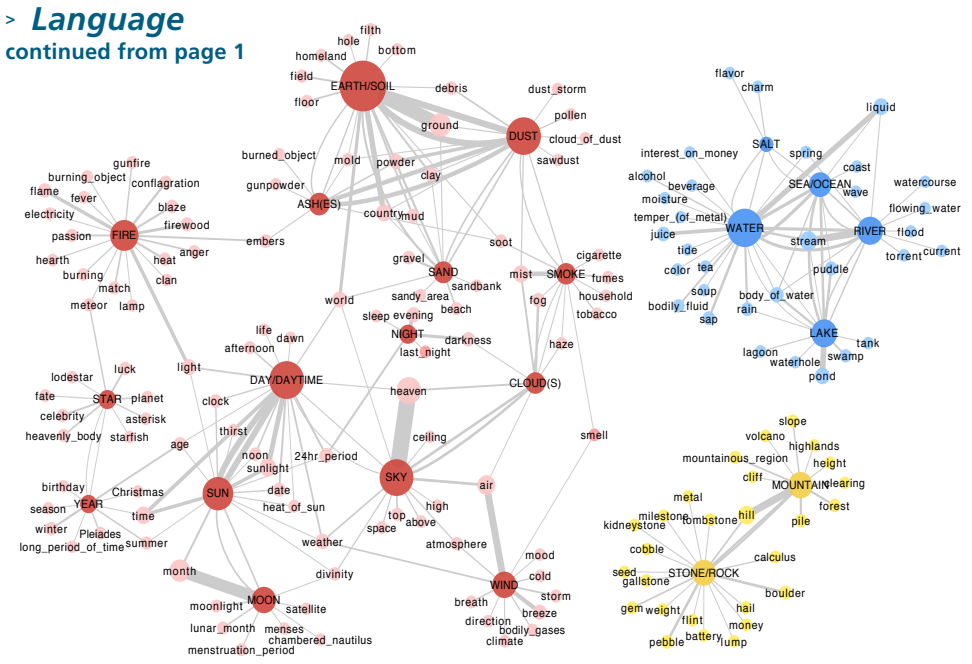


A network inferred from translated word meaning data. Concepts are linked when polysemous words cover both concepts. Swadesh words (the starting concepts) are capitalized. The size of a node and the width of a link to another node are proportional to the number of polysemous words associated with the concept and with the two connected concepts, respectively. Three distinct clusters — red, blue, and yellow — are identified, reflecting a possible human conceptual structure.

English into 81 diverse languages, then back into English. Based on these translations, a weighted network was created. The structure of the network was used to compare languages' ways of partitioning concepts.

The team found that the translated concepts consistently formed three theme clusters in a network, densely connected within themselves and weakly to one another: water, solid natural materials, and earth and sky.

"For the first time, we now have a method to quantify how universal these relations are," says Bhattacharya. "What is universal – and what is not – about how we group clusters of meanings teaches us a lot about psycholinguistics, the conceptual structures that underlie language use."

The researchers hope to expand this study's domain, adding more concepts, then investigating how the universal structure they reveal underlies meaning shift.

Their research was published recently in *PNAS*. Among the paper's eight co-authors are five SFI-affiliated researchers: SFI Professor Cris Moore; External Professors D. Eric Smith and Jon Wilkins, and Youn and Bhattacharya. ■

RESEARCH NEWS

Anomalous economists to convene at SFI

Last year, at Her Majesty's Treasury in London, a global team of economists calling themselves Curriculum Open-access Resources for Economics, or CORE, launched an ambitious, unconventional project.

This February, CORE will meet at SFI to discuss how to make sure their anomalous efforts have a lasting impact on how students learn economics – and the way they think about science.

"CORE is teaching economics as if the last 30 years had happened," says SFI Professor Samuel Bowles, one of the group's founders, referring both to the financial crisis of 2008, which took many economists by surprise, and the growing acknowledgment among economists that not everyone is entirely selfish as traditional economic theory asserts.

CORE's interactive ebook, *The Economy,* is not your usual Econ 101 fare. First, it emphasizes identifying and modeling empirical regularities rather than developing mathematical models from a set of abstract, often dubious assumptions about economic behavior.

Second, it focuses on fundamental issues that are connected to economics but that other texts tend to ignore – issues like financial instability, wealth creation in capitalist societies, inequality, and environmental sustainability.

Students come to economics wanting to tackle those problems, and recent innovations in economics have a lot to say about them, wrote CORE director and University College London professor Wendy Carlin recently in the *Financial Times*.

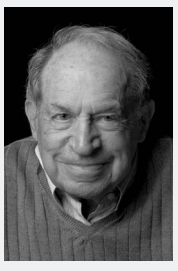
As striking as the book's content is the price. Competing textbooks sell for upwards of $200, but *The Economy* is free and available to anyone with an internet-connected device at www.core-econ.org.

"Meeting at SFI is a natural for CORE," says Bowles. "We are teaching first-year students to think about the economy as a complex, dynamical system and to beware of static metaphors and disciplinary parochialism."

The question now, Bowles says, is how to ensure that CORE continues to grow and mobilize the diverse inputs from teachers, students, and other users.

Others contributing to CORE are SFI External Professors Rajiv Sethi and Simon DeDeo. ■

Simon Levin, a member of SFI's Science Board, has been selected to receive the U.S. National Medal of Science – the nation's highest honor for achievement and leadership in science. Levin's research focuses on connecting macroscopic patterns at the level of ecosystems and the biosphere to behaviors and evolutionary mechanisms that operate at the level of individual organisms. Though he primarily focuses on biological and ecological systems, he has applied his insights into structure and organization to the study of other complex systems, such as socioeconomic systems and infectious disease epidemics. Levin and eight other awardees will receive their medals during a White House ceremony in 2016.



SFI's David Pines is to receive the American Physical Society's 2016 Julius Edgar Lilienfeld Prize for his contributions to physics over his 65-year career and for his "effectiveness in communicating these discoveries and a new 'emergent' paradigm to the broader scientific community." As the prize recipient, Pines is called on by the APS to deliver three lectures: at a society meeting, at a research university, and at a predominantly undergraduate institution. He will give the first lecture at the March meeting of the American Physical Society in Baltimore; he plans to give a preview of that talk during a March 8 colloquium at SFI.

SFI Professor Cristopher Moore has been elected to the 2016 class of fellows of the American Mathematical Society for "contributions to randomized algorithms and quantum computing, bridging mathematics, statistical physics, and theoretical computer science." Moore and other fellows were honored as part of a January 8 reception during the Joint 2016 Mathematics Meeting in Seattle.

SFI Professor David Wolpert has been named a fellow of the Institute of Electrical and Electronics Engineers (IEEE) for his contributions to optimization, machine learning, distributed control, and game theory. The elevation of an IEEE member to fellowship recognizes that scientist's extraordinary record of accomplishments. The number of fellows selected in any one year represents less than one-tenth of one percent of the IEEE voting membership. ■

Can online data really enhance public health surveillance?

Health-related data submitted by patients online and via social networks are increasingly plentiful. A recent paper in *EPJ Data Science* reported the findings of a 2014 meeting at SFI, during which scientists and public health officials evaluated the state of so-called Novel Data Streams (NDS) and outlined a conceptual framework for integrating such data into current public health surveillance systems.

"Novel Data Streams encompass a broad set of sources from internet search data to social media posts to Wikipedia access logs, even restaurant reservations and reviews," says the study's co-author, SFI Omidyar Fellow alum Ben Althouse.

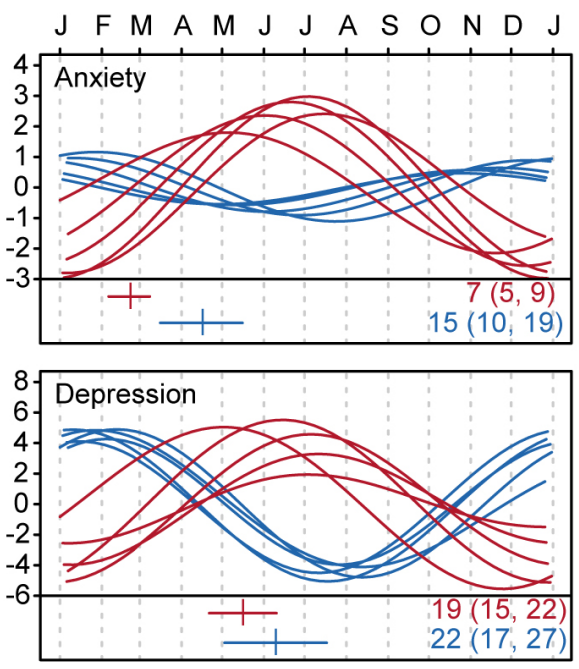
A well-known example of an NDS surveillance system is Google Flu Trends, developed in 2008, which translated Google search queries into an estimate of the number of individuals with influenza-like illnesses (ILI) visiting primary healthcare providers.

While the system initially performed well, it fell into criticism due to prediction failures across influenza seasons and uncertainty about whether prediction of ILI rates two weeks before predictions from the CDC adds value to the existing surveillance systems available to public health authorities.

Nonetheless, "novel data streams have a bright future," says SFI Omidyar Fellow alum and co-author Sam Scarpino. "Soon, surveillance systems could be nearly instantaneous and deliver on very fine geographic scales."

NDS might also extend surveillance to places with no existing systems and improve the dissemination of data, and could potentially measure unanticipated events, such as syndromes associated with a new pathogen not currently under surveillance.

"We have to be rigorous in our evaluation and validation of these systems before they're implemented," Althouse cautions. "These systems show tremendous potential, so we need to make sure we get them right." ■



Seasonal changes in Google search queries for anxiety (top) and depression (bottom) in the U.S. (blue) and Australia (red). Searches were wavelet transformed to isolate the seasonal component. Searches for a majority of mental illnesses peak in the winter. (Image: Ben Althouse)

GSSS 2016: Cities as crucibles of sustainability solutions

The best places to address issues of global sustainability are cities, which today are home to the majority of earth's people and which produce some 70 percent of the world's carbon emissions.

For two weeks in Santa Fe this summer, participants in the 2016 Global Sustainability Summer School – including scientists, policy makers, and business leaders from around the world – will examine the environmental and socioeconomic challenges associated with urban areas, drawing on examples of how today's cities are using science, innovative policies, data, and technology to address these challenges.

Treating cities and neighborhoods as complex systems, participants will explore systemic solutions to the interrelated issues of energy and transportation, economic growth, health, crime, and environmental quality.

"This school will focus on cutting-edge work that is being done now to understand and address these issues," says SFI Professor Luis Bettencourt, the school's director. "And not just solutions, but how to create a process that can lead to a solution. That's the nature of problems of sustainability; you have to make continuous progress toward making things better, and that takes the kind of interdisciplinary strategic thinking we promote at the Santa Fe Institute."

The school, which runs July 25-August 5, 2016, is open to scientists at all stages of their careers, business and technology leaders, and policy makers at the national and local levels. Applications may be submitted through February 23, 2016. ■

64 scholars participate in first SFI complexity school in India

SFI and the Indian Institute of Science Education and Research hosted the first India Complex Systems Winter School in Mohail, India in December. More than five dozen grad students and postdocs in the sciences and social sciences participated in an intensive two-week introduction to complex behavior in mathematical, physical, living, and social systems, with many of the lessons taught by SFI faculty. Above: Donepudi Ravi Teja (University of Hyderabad) and Aaron Sebastian Taudt (University Medical Center Groningen) discuss their research on a bridge at the Chandigarh Rock Garden. Left: Sagar Chakraborty (Indian Institute of Technology Kanpur) gives a tutorial on fractals. (Photo by Prateek Verma)

Image: istockphoto.com

Paper's findings suggest a science of city skylines

A city's skyline is more than a silhouette, according to new research by SFI's Markus Schläpfer and Luís Bettencourt and their colleague Joey Lee published December 3 on arxiv.org. The researchers analyzed dimensions of almost five million buildings across North America and in 12 cities of varying sizes. They found that building shapes could be characterized as a function of population. As a city's population rises, so do its buildings, which become more energy efficient – up to a point. Buildings diffuse less heat as they move from flat to cube-like, but then they lose efficiency again as tall, needle-like skyscrapers proliferate, as in New York and downtown Boston. An article in *MIT Technology Review* points to the potential for a "science of skylines" that might help plan sustainable cities.

Exploring virtuous cycles of renewable energy development

A report by SFI External Professor Jessika Trancik's lab at MIT, issued just before the Paris climate talks in December, called for more realistic energy policies that employ complex systems approaches. The report analyzes development and cost profiles for various wind and solar technologies over the past four decades, identifying nonlinear dynamics, such as positive feedback loops, that rapidly drive down the costs of low-carbon technology as technologies improve and as production increases. "Commitments made in international climate negotiations offer an opportunity to support the technological innovation needed to achieve a self-sustaining, virtuous cycle of emissions reductions and low-carbon technology development by 2030," they wrote. Trancik presented the report at the White House on November 13. ■

Two elected to SFI's Board

Ted Rogers

SFI's Board of Trustees welcomed two new members, Theodore C. Rogers and Eugene Stark, during SFI's biannual symposium November 12-14, 2015.

Ted Rogers is chairman and founding partner of American Industrial Partners, a private equity firm that invests in North American industrial businesses. Before founding AIP, he chaired Bucyrus International, Great Lakes Carbon, and NL Industries and served as president of Armco Steel Corporation's National Supply Company, following service in the U.S. Navy.

Gene Stark is a retired Los Alamos National Laboratory researcher and manager who has served in the leadership of family firms Plastic Components and Arlington Industries. He serves on the boards of the Santa Fe Opera, Los Alamos National Bank, and the International Dominican Foundation and was an early supporter of Open Courseware at MIT.

Gene Stark

More about Rogers and Stark at www.santafe.edu/news. ■

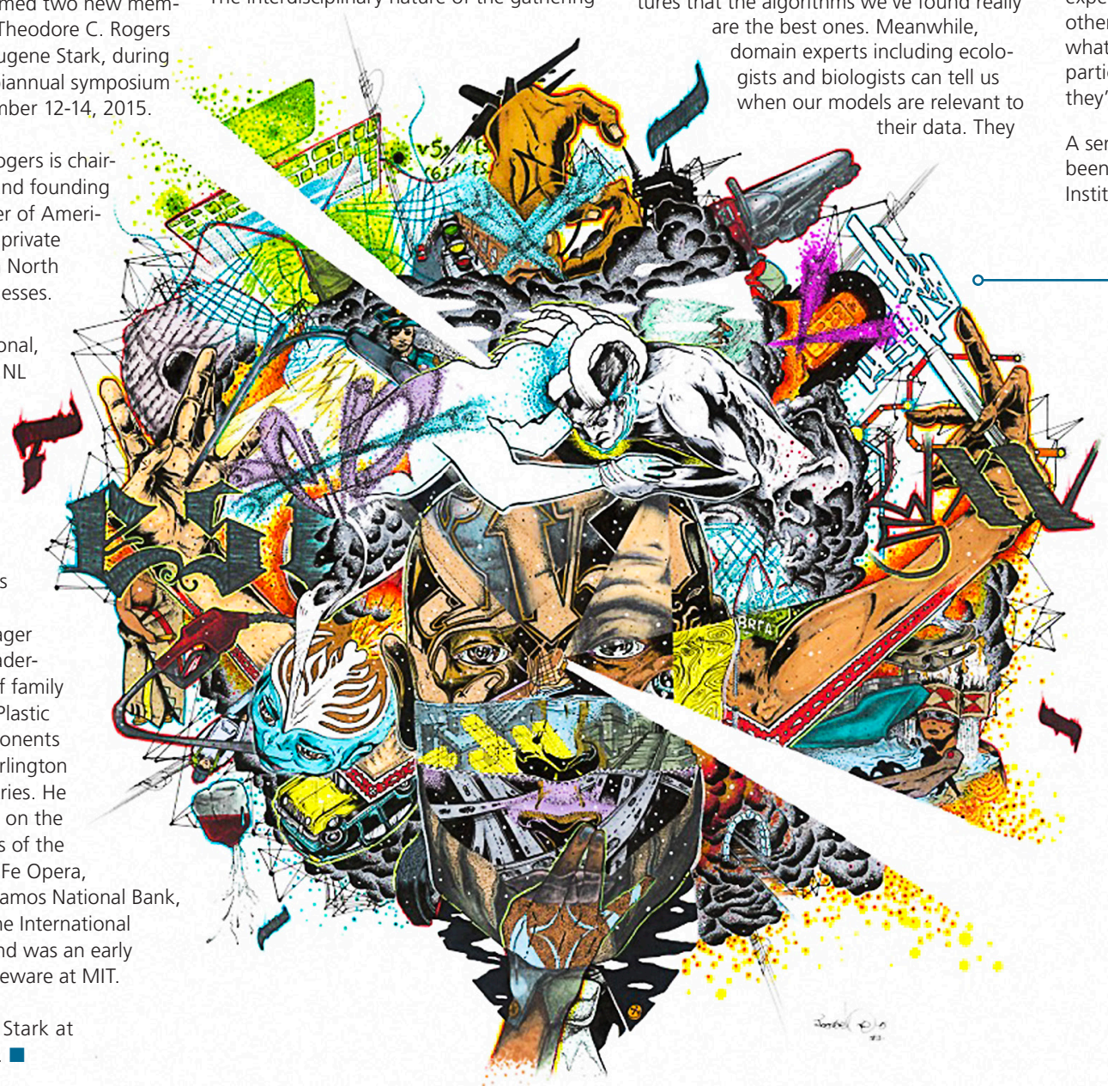
> *Networks* **continued from page 1**

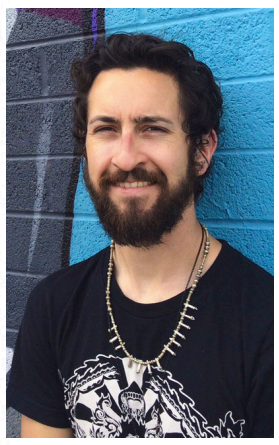
rithms appropriate for rich datasets and study the behaviors that emerge. But there is more to learn.

The interdisciplinary nature of the gathering was the key. "Physicists can make good guesses about algorithms and how well they perform," he says. "Computer scientists can in some cases prove the physicists' conjectures that the algorithms we've found really are the best ones. Meanwhile, domain experts including ecologists and biologists can tell us when our models are relevant to their data. They connect the theory to practice."

"SFI allowed us to gather a unique mix of experimenters, theorem-provers, and domain experts," he says. "We learned from each other about what questions we ask, and what we regard as a good answer. Many participants said this was the best meeting they've attended in years."

A series of SFI workshops on networks has been sponsored, in part, by the U.S. National Institute of Standards and Technology. ■





Joerael Elliott, an artist spending the winter at the Institute interpreting various SFI research themes, created this piece, which he calls "computational cultural complexity." He says: "In my illustration I revolved my area of focus around Los Angeles where I lived for four years. In this piece I inject symbolism that depicts the nature of conflict and alliance that arise to shape neighborhoods and cities culturally. I chose to render gang symbolism to illustrate the territorial complexity of systems that occur in cities such as LA." Elliott grew up in West Texas and spent several years in Phoenix, Los Angeles, and other western U.S. cities immersed in the arts communities. He recently moved to Santa Fe and is often found drawing in the Institute's shared spaces. See more of his work at www.joerael.com.

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> *Migration* **continued from page 1**

explore how these rules scale up to group functioning.

He is interested in differences in how group size affects crossing speed and success rate, and whether the animals have different social interactions on and off the ice. Berdahl suggests large groups may act as a distributed sensor array in detecting environmental gradients – in this case, ice thickness – or use the social information of where others have crossed in deciding which path to take. ■

Upcoming community events

SFI Community Lecture, Tuesday, January 19, 7:30 p.m., The Lensic Theater (211 W. San Francisco St.) — DNA, Love, and Gender. When it comes to human behavior, some traits are neither nature nor nurture, but something altogether different. That "something" is epigenetics, the science that helps explain how the environment, including some social interactions, alter DNA. In this talk, Dr. Karissa Sanbonmatsu explores epigenetics and its implications for autism, addiction, depression, Alzheimer's, and even love. She will discuss her latest research, revealing how long RNA molecules (DNA's molecular cousins) may be the key to understanding many epigenetic phenomena.

Sanbonmatsu is a principal investigator at Los Alamos National Laboratory studying the molecular machine that implements the genetic code. With over a half-million views, her 2014 TEDx talk revealed how she found her way to the study of epigenetics.

SFI Community Lecture, Monday, February 29, 7:30 p.m., The Lensic Theater (211 W. San Francisco St.) — The Urban Species: How Domesticated Humans Evolved. Modern humans are building megacities – and networks of megacities – at an unprecedented scale. Author and journalist Annalee Newitz compares today's urbanization phenomenon to that of the Neolithic period roughly 9,000 years ago, when humans first began living in sedentary communities. That shift prompted massive social, biological, and technological changes, creating the first "domesticated" humans. Using history as a guide, Newitz explores the evolutionary upheaval that modern people may have set in motion, and what it might mean for us as a civilization.

Newitz is the technology and culture editor of *Ars Technica* and founder of *io9*. She holds a PhD in English and American Studies from UC Berkeley. Her most recent book is *Scatter, Adapt, and Remember: How Humans Will Survive a Mass Extinction.*

SFI's 2016 Community Lectures are made possible through the generous support of Thornburg Investment Management and The Lensic. 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 @SFIlive.

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