Spring 2017

# Parallax

The newsletter of the Santa fe Institute

# SFI's April symposium explores complexity of new data worlds

Optimists look to new, large, complex datasets to help spot business trends, prevent disease, and combat crime. Skeptics know that floods of data stream into science, business, and government already, and increasingly overwhelm their current systems of analysis and application.

Science in particular has begun to probe the possibilities and limits of Big Data — and is making headway in building new analytic tools, finding new correlations, and achieving theoretic progress.

But what's next on the data frontier?

SFI's 2017 Science Board Symposium will peer beyond these challenges to ask what happens when large, complex data sets collide. Participants will inquire into the meaning of facts and evidence, and what new challenges arise when tools of computation and machine learning merge with fundamental science.

"Data, statistics, and machine learning are insufficient. Fundamental science is required for robust prediction and explanation," says SFI President David Krakauer. "As complexity scientists, our role is to ask how the sciences of complex systems can augment the power of data analytics. What new ideas, frameworks and methodologies will result from connecting powerful computing platforms with powerful unifying theories, and how might these influence business practice and policy?"

Krakauer is co-organizing the April 20-21 symposium, "The Complexity of New Data Worlds," with Science Board Co-Chairs Daniel Schrag (Harvard) and Mercedes Pascual (University of Chicago).

"Of significant interest to complexity science," says Krakauer, "is how several data sources can be combined and then best be analyzed to reach new forms of consensus in the policy, security, and environmental realms."

For example, it is now possible, for the first time in human history, to track individual movements and interactions using cell phones, geotagging of photos, and mining of social media activities. What happens when your online activities are further synced with the world of bus schedules, stock markets, weather, and other people's movements and interactions?

In addition, machine learning and artificial intelligence promise vastly improved capabilities for analyzing new combinations of data. These computational tools present opportunities for predicting both behaviors and consequences, and raise questions as to how they should be used to augment decision-making in policy and public planning.

> MORE ON PAGE 4

# Postdocs prep for 72 *more* hours of science

Last April, 15 SFI postdoctoral fellows rented a house at the edge of Santa Fe and hunkered down for a novel, ambitious task: In just three days, they would choose a project, conduct research, and write an academic paper. It was 72 Hours of Science — 72h(S) for short. Now, they are getting ready to do it again May 8-11.

Each postdoc arrives with an idea for a new project — something they haven't brainstormed with anyone else — and the group votes to choose a single idea. The goal is to find an interesting research project that is topically broad but also narrow enough to tackle in three days. What results is truly collaborative, owned equally by all the authors.

"Last year, our project managed to touch on evolutionary biology, social science and epidemiology. It used everyone's expertise," says Chris Kempes, an SFI Omidyar Fellow who has become the de facto spokesperson for the group. "This year, we might be less ambitious. The project will still require everyone's effort, but may not draw on each person's particular field."

While the fast-paced nature of 72h(S) isn't the direction anyone wants to push science overall, the experience of working so intensely on one project together strengthened relationships and initiated new collaborations among SFI's postdocs, says Kempes. "It gave everyone the opportunity to collaborate with everyone else."

Most of SFI's current postdoctoral fellows will be participating for the second time, but for SFI's two newest fellows, this is an event they've anticipated for months. "We have no idea what we're going to do, but I'm looking forward to seeing how other postdocs approach problems," says Joshua Garland, an Omidyar Fellow. "Every day at SFI, you get lots of different opinions. 72 Hours of Science is like super-concentrated SFI."

"At SFI, everybody has tons of crazy ideas all the time, but it's hard to get enough people together to act on those ideas," says Elizabeth Hobson, an ASU-SFI fellow. "This could be a way of tackling those and doing some really innovative science."

# Return of the Y2K bug

If you find yourself in the south this spring, you'll have a chance to witness a predictable plague.

A species of *Magicicada* emerges after 17 years underground in swarms so vast they overwhelm their predators. Nearly each year sees an emergence of a given subpopulation in the U.S. Numbers vary by region; this year, Brood VI will rise in the mountains of Georgia and South and North Carolina (and elsewhere in patches) as it last did in the year 2000.

Despite extraordinary variation in brood size and distribution, boundaries between them remain sharp and steadfast, according to more than a century of records.

Meanwhile, pistachio farmers in California are keen to find ways to disrupt their crop's synchrony for economic reasons, explains External Professor Jon Machta, a statistical physicist at University of Massachusetts, Amherst. The trees' two-year pattern of high and low yields often fall into phase across orchards, frustrating growers who prefer a more uniform production and income.

How and why these ecological systems synchronize is what the "Origins of Large-Scale Spatial Synchrony in Ecology" working group will explore April 18-20. This third annual meeting builds on their earlier work that considered variations, measures, and indicators of synchrony — that is, spatially extended populations all behaving in the same way in time — and "extends it to more realistic situations," says Machta, by developing models based on those in statistical physics and nonlinear dynamics.

> MORE ON PAGE 4

# BEYOND BORDERS

*The SFI community gathered January 31 to discuss the newly-issued Executive Order 13769. Following SFI's community discussion, President David Krakauer wrote the following statement:*

## THE DANGERS OF SIMPLICITY IN A COMPLEX WORLD

The recent ban on immigrants to the United States is a dangerous and simplistic step that ignores the complexity of our networked world.

The historian Isaiah Berlin declared, "We are doomed to choose, and every choice may entail irreparable loss." We live in a complex world where there are few benefits without costs, and where unintended consequences multiply.

In a complex world, cooperation, collaboration, discussion, evidence, and diversity become the pillars upon which we build society. The free exchange of ideas, the rigorous pursuit of knowledge, and the maturity that comes with abandoning simplicity, ideology, and prejudice lead us toward a better world for everyone. This is the wish of all of our political parties.

In recent weeks we have seen complexity cast aside, and national and economic simplicity pursued without debate, with scant consideration for the human and institutional repercussions that this will produce.

Over the last 30 years the Santa Fe Institute has helped to build tools and theories, train students, faculty, and representatives from numerous companies around the world, and confront and deal with seemingly insurmountable complexity — from economic collapse to the devastation of global pandemics.

If there is one thing we have learned, it is that however hard we try, complexity does not go away and we ignore it at our peril.

Let's face up to truly threatening challenges, and come together to solve the hardest problems that endanger the Earth itself: economic inequality, market catastrophes, antibiotic resistance, spiraling technological instabilities, cascading conflicts, and the numerous challenges of global population, energy, and climate.

There is only one Earth and we shall never improve it by acting as if life upon it were simple. Complex systems will not allow it.

— David Krakauer
*President, Santa Fe Institute*

## FROM THE EDITOR

You really do need to read another newsletter — this one. Like the Santa Fe Institute, *Parallax* lets you to step outside day-to-day, immediate experiences and join the quest for enduring patterns. Whether you're struggling to do business in a data-driven world, or just wondering why the cicadas have returned, *Parallax* helps you see life through the lens of complex systems science.

John German, SFI's longtime communications director, thought of SFI science as a "macroscope" for viewing and making sense of our complex world. Through forward-looking features, updates on recent research, and news about community events, he designed this newsletter to serve the same function — to share SFI's unique, big-picture perspective with our extended networks.

Thank you, John, for your sixty-some newsletters and 10 years of service.

— Jenna Marshall

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## SFI IN THE NEWS

*The New York Times*, *Mercury News*, *East Bay Times*, and santafe.edu honor **Kenneth Arrow**, one of SFI's intellectual architects who passed away on February 21.

*Quanta Magazine* features **David Wolpert** and **Artemy Kolchinsky**'s insights into how living systems use information to avoid death by equilibrium.

In SFI's complexity series for *The Christian Science Monitor*, **Seth Blumsack** writes about the power grid as a complex system that defies our best efforts to prevent widespread blackouts.

*The Atlantic* relays Professor **Sid Redner**'s latest work on foraging strategies in an article titled "How Math Can Tell You When to Move on in Life."

In *WIRED UK*, President **David Krakauer** writes that the threat posed by intelligent machines is not humanity's true obstacle. Rather, "the evolution of human intelligence has always been about overcoming our soft organic matter."

In a feature article on SFI's creative culture, Robert Wolcott of the *Harvard Business Review* asks President **David Krakauer** about "Leading People Too Smart to Be Led."

A science-of-science essay by External Professor **Aaron Clauset**, Omidyar Fellow **Dan Larremore**, and Roberta Sinatra of Central European University is featured in *Pacific Standard* and several international news outlets.

In an article titled "Santa Fe Institute game theory course takes on real-life scenarios," the *Santa Fe New Mexican* gives playful treatment to postdoc **Justin Grana**'s new game theory tutorial. The free tutorial is available through Complexity Explorer, SFI's online education portal.

# Shopify's Toby Shannan: The vocabulary of complexity extends to business

When he heard SFI President David Krakauer on a popular podcast last year, Toby Shannan didn't know exactly how SFI could help him, but the interview prompted a realization: Some of his company's biggest challenges were the byproducts of complexity.

Shannan is the vice president for customer support at Shopify, which provides services for businesses and entrepreneurs who want to set up shop on the internet. Shopify joined SFI's Applied Complexity Network (ACtioN) in late 2016.

Building an online storefront requires combining domain support, web design, filters, shopping carts, social media, and more into an integrated interface that becomes the customer experience: it's a classic "whole is greater than the sum of the parts" phenomenon, says Shannan.

Shopify's challenge is to simplify how its 400,000 customers solve their problems as new online services and technologies become available. This compels the company to make good choices in a universe of software possibilities, says Shannan, by picking out products that are likely to lead to a greater degree of client satisfaction — and fewer calls to technical support.

Before the podcast interview, he had been mulling over a concept for a heuristics-based decision tool to assess the complexity of a candidate software product — essentially an objective way to ask: Is there math for scoring a product based on how difficult it is to use?

When he discussed the idea with SFI VP for Strategic Partnerships Will Tracy, Tracy invited

> MORE ON PAGE 4

# Luís Bettencourt to direct new urban innovation center

SFI Professor Luís Bettencourt has accepted an offer to direct the Mansueto Institute of Urban Innovation at the University of Chicago. Starting July 1, Bettencourt will transition to SFI's external faculty as he assumes his new role as Pritzker Director of the Mansueto Institute for Urban Innovation and Professor of Ecology and Evolution at the University of Chicago.

During his time at SFI, Bettencourt and his collaborators have advanced a multidisciplinary science of cities, combining concepts from complex systems with comparative analysis of urban data from cities and neighborhoods around the world. Their fundamental insights into urban scaling include the idea that urban centers sustain and accelerate general socioeconomic processes that generate innovation, human development, and economic growth in human societies.

"This is a special moment because the world is becoming urban, so the experience and struggles of most people are becoming in many ways more similar. Cities are taking the initiative to address problems of opportunity, quality of life and sustainability, and because of these commonalities and the growing availability of data, there's the realization that many of these difficult problems can be approached more systematically and more scientifically," Bettencourt says. "SFI is a great experimental incubator in this multidisciplinary field of urban sciences. As the field grows, one thinks about how it can engage more with education and practice, and the University of Chicago is an ideal place to put all that together. They have a great history and tradition in many of the sciences that frame our understanding of cities."

"Luís has had a fascinating and diverse career in complex systems," says SFI President David Krakauer. "The offer to direct the new Mansueto Institute for Urban Innovation at the University of Chicago, and Luís's professorship in ecology and evolution, comes at an opportune time in his career and will provide exactly the kind of amplifying infrastructure for complexity science that Luís has been analyzing and explaining through his own work. It is a tremendous opportunity for Luís, complexity science, and the Santa Fe Institute."

Bettencourt began collaborating with SFI in 2007 as an external professor based at Los Alamos National Lab. In 2011, he transitioned to a full-time position at SFI where he is a professor.

Alongside his urban research, Bettencourt has been exploring deep ideas and models related to statistical mechanics of non-equilibrium systems, phase transitions in networks, processes of learning and innovation, disease transmission, and sustainability science.

These may seem surprisingly diverse, but a web of connection unifies Bettencourt's research projects, Krakauer notes. A systems approach to these varied fields results in new and powerful insights on multidisciplinary subjects, such as the study of cities and urbanization. This kind of approach is the hallmark of complexity research.

"We wish Luís and Laura and their family the very best of complex contingencies (luck!) in their future careers," Krakauer says, "and we very much look forward to future collaborations between SFI, the Mansueto Institute, and the University of Chicago."

# New SFI Postdoctoral & Omidyar Fellows

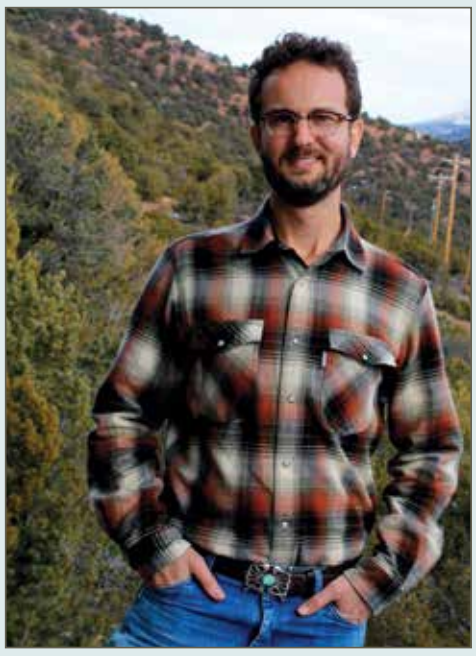
## ANDY ROMINGER

### *A macroscopic view of life*

"The goal of understanding and predicting biodiversity dynamics comes at a critical moment when human systems are disrupting those very dynamics," explains new Omidyar Fellow Andy Rominger, neatly summarizing his motivations to elucidate the profound connections across ecology and evolution and to unify them in "a simple set of universal governing mechanisms."

This pursuit has guided him through his undergraduate degree in biological sciences at Stanford University and his Ph.D. in environmental science, policy, and management from UC Berkeley. He brings his recent experience as a postdoctoral scholar with the Berkeley Initiative in Global Change Biology to SFI with the intention to create "a foundation for how global change may drive future shifts in ecology and evolution."

Rominger's approach uses principles from statistical physics and data science to confront theory with real-world data. He advocates the hypothesis that universal patterns of biodiversity emerge from a blend of statistical mechanics of large systems and non-equilibrium dynamics bestowed by evolutionary history onto biological systems.



At SFI, Rominger anticipates exploring connections between biology and disparate fields. "I am thrilled by the prospect of collaborating with open-minded researchers from diverse backgrounds who revoke disciplinary constraints in order to advance science."

He plans to join SFI this summer.

## MICHAEL PRICE

### *The roots of economic choice*

Humans make economic decisions all the time: what type of toothpaste to buy, whether to borrow for a new house, what prey to hunt, and even when to reproduce. Our brains — and therefore how we make decisions — are the product of millions of years of evolution. Michael Price, a 2017 ASU-SFI Center Postdoctoral Fellow, is exploring ways to link economic and evolutionary theories to better understand human decision-making processes.

Price worked at Raytheon Space and Airborne Systems after earning his B.S. in physics from Harvey Mudd College. As part of his Ph.D. in anthropology from Stanford University, he studied economic decision-making in households in an eastern Indonesian village. He has continued his research on the evolution of economic preferences as a postdoctoral researcher at Pennsylvania State University.

Understanding the evolutionary roots of personal preferences may seem fairly innocuous, says Price. "But it leads to some surprising conclusions with important practical implications for how to address vexing real world

problems such as the persistence of extreme poverty and inequality." While at SFI, Price hopes to expand his research for a systems-level look at wealth and poverty, risk-taking behavior, and the interplay between people, institutions, the environment, and disease.

Price plans to join SFI this summer.

## JACOPO GRILLI

### *Ecology's underlying principles*

What are the simplest rules and most minimal assumptions that bound complex phenomena? It's a question that has driven incoming Omidyar Fellow Jacopo Grilli through his undergraduate and master's studies in physics at the University of Milan, and later at the University of Padova, where he obtained his Ph.D.

Since 2015, Grilli has worked as a postdoctoral scholar at the University of Chicago's Department of Ecology and Evolution. "My work focuses mainly on community ecology," he says. Engaging both conceptual problems and data-driven projects, he aims to bridge theoretical results with observed patterns. "I want to understand how the interplay between ecological interactions and stochasticity shapes biodiversity," he says.

He is also interested in genomics and cell physiology. He has explored how scaling patterns across organisms and environmental conditions suggests the existence of underlying general principles. And, he studies the connection between stress response and recovery and aging, using the nematode *C. elegans* as a model organism.

Grilli looks forward to the interdisciplinary opportunities available at SFI. "I like to collaborate with

people from a diversity of backgrounds, from mathematics to experimental biology," he says. "The Omidyar program provides the possibility of intellectual and scientific freedom simultaneously with a high quality and adjustable leadership training. It perfectly meets what I need at this stage of my scientific career."

He plans to join SFI in January 2018.

## KEYAN GHAZI-ZAHEDI

### *A theory of morphological intelligence*

For the average person, lifting a teacup is no great feat of concentration. The softness of the human hand and the friction of its skin allow us to grab fragile objects without the need to focus on precisely controlling the position of each finger. During such tasks, the brain outsources some its computation to the body and environment — postdoctoral fellow Keyan Ghazi-Zahedi aims to understand exactly how these computations are distributed among brain, body, and environment.

"Biology provides us with numerous examples of functions that are normally attributed to the brain but result, at least partially, from the interactions of the body with the environment," says Ghazi-Zahedi. "Unfortunately, there is no theory that accounts for the different kinds of morphological contributions to intelligence." Finding such a theory is what motivates his research, both at SFI and at his home institutions in Germany.

Ghazi-Zahedi currently is a senior researcher at the Information Theory of Cognitive Systems Group at the Max Planck Institute for Mathematics in the Sciences and a lecturer at the University of Leipzig. He earned his Ph.D in neuro-informat-

ics from the University of Osnabrück, having conducted his Ph.D. project at the Fraunhofer Institute for Autonomous Intelligent Systems. He also holds an M.Sc. in computer science from the University of Tübingen.

Ghazi-Zahedi plans to spend May through October at SFI.

# Complexity postdocs regroup to build on collaborations

This July, two cohorts of early-career complexity scientists will regroup at SFI for open collaboration and some open air.

The second Postdocs in Complexity Conference brings together many of the same participants who attended the first conference in January. Fifteen of these postdoctoral fellows are based at SFI and 32 are James S. McDonnell Foundation (JSMF) fellows who hail from academic institutions all over the globe. The goal of these bi-annual conferences is to build community and seed collaborations amongst the rising stars of complex systems science, and to establish best practices for the emerging field.

Where the January conference focused primarily on leadership and career-building topics, the July conference will hone in on research, giving the fellows more free time to collaborate and brainstorm ideas.

"This second meeting will be great for collaboration," says ASU-SFI fellow Elizabeth Hobson. She and JSMF fellow Eleanor Brush are working together on an agent-based model of animal signals and learning. "Now that we all know each other from the first meeting, we can turn some of our shared interests into new projects."

Jakob Runge (JSMF) and Joshua Garland (SFI), who met at the January conference, have been collaborating on developing new techniques aimed at extracting and analyzing the information locked away in deep polar ice cores.

Hilary Skolnik, SFI's Postdoctoral Fellows Program Manager, says that given this meeting's focus on research, she expects many more collaborations to result from the July conference.

As part of the second conference, the postdocs will share their research by giving lightning talks — 5 minutes, with 5 minutes for Q&A. They'll also take a field trip to Kasha-Katuwe Tent Rocks National Monument, southwest of Santa Fe.

The productive "research jam sessions" from the January conference are making a comeback in July. The hour-long sessions prompt postdocs to collaborate on questions that transcend individual disciplines.

"It gives them a chance to work together to come up with some novel solutions to problems they may be facing," Skolnik says.

Also on the agenda are Carnegie Mellon's Carol Frieze and Geoff Kaufman. Their program, BiasBusters@CMU, focuses on diversity and implicit bias.

"It is an issue that is facing academic selection more than ever, and one that doesn't seem to be addressed often enough," Skolnik says. "We believe that it is important to raise awareness for everyone but especially for our participants, many of whom will be leaders in their fields and will be hiring and managing research and administrative staff in the future."

## ACHIEVEMENTS

SFI External Professor **Mahzarin Banaji**, the Richard Clarke Cabot Professor of Social Ethics and Chair of the Department of Psychology at Harvard University, has been selected to receive this year's Association for Psychological Science's William James Fellow Award for lifetime contributions to the basic science of psychology. Banaji's research centers around studied social attitudes and beliefs in adults and children, with a focus on their implications for questions of individual responsibility and social justice in democratic societies.

**Alan Perelson**, a senior fellow at Los Alamos National Laboratory and an SFI external professor and Science Board member, will receive the American Physical Society's 2017 Max Delbruck Prize in Biological Physics for "profound contributions to theoretical immunology, which bring insight and save lives." Perelson has made fundamental contributions to understanding the immune system, elucidated many features of HIV infection including the need to treat the infection with combination therapy, and established basic principles that led to the new cures for hepatitis C infection.

The American Physical Society has named SFI External Professor **Raissa D'Souza** a fellow for her work in the statistical physics of complex systems. D'Souza is professor of computer science and mechanical and aerospace engineering at UC Davis. Her research focuses on mathematical models of self-organization, phase transitions, and the structure and function of networked systems. The number of APS fellows elected in a given year is less than one-half of one percent of the APS membership.

The White House has appointed **Jerry Sabloff**, an SFI external professor and past president, as chair of the federal Cultural Property Advisory Committee. The Committee, created to support the United States' role as a signatory to a 1970 UNESCO convention restricting illicit import and export of culturally important items, works under the U.S. Department of State to advise the White House on responses to international requests for help in protecting archaeological items.

**Jennifer Dunne**, SFI's Vice President for Science was named Fellow of the Ecological Society of America for her deep and central contributions to the theory of food web analyses, including extension to paleo food webs. Dunne's research encompasses analysis, modeling and theory related to the structure, dynamics, and function of complex ecological networks.  Dunne was also profiled in Methods in Ecology and Evolution's official blog post on "Influential Women in Ecological Network Research."

**Murray Gell-Mann**, SFI Life Trustee and Distinguished Fellow, and **Ole Peters**, SFI External Professor, co-authored Evaluating Gambles Using Economics, which was named the AIP Journal Chaos' most read paper of 2016. In February 2016, Peters, based at the London Mathematical Laboratory, and Gell-Mann published an alternative model for evaluating gambles where humans act to optimize their wealth as time passes. Their approach was first articulated in an SFI working paper.

SFI Science Board member and External Professor **Lauren Ancel Meyers** received the Joseph I. Lieberman Award for Excellence in Science and Technology from the Center for Excellence in Education. Ancel Meyers is a professor of integrative biology at the University of Texas, Austin, where she researches the dynamics of disease transmission.

Google has recognized SFI postdoc **Brendan Tracey** for his contributions to codebases and his dedication to open source communities. Tracey is working on gonum.org, a set of scientific libraries for the Go programming language.

**New data worlds** *(cont. from page 1)*

"Such configurations suggest new forms of prediction no longer based on fundamental mechanisms," says Krakauer. "They also generate new questions: How trustworthy are predictions that arise from these tools? What new challenges do they present for privacy? What can we do to address the large-scale violations of security they portend?"

An increase in data availability also holds implications for addressing skepticism of science in evolution, climate change, and financial instability.

"The abundance of data and improved prediction certainly aid us in reducing our own uncertainty in these areas," says Schrag. "But we know well that more data does not equal more consensus. We should like to understand whether, and how, these new data worlds interact with widespread public skepticism and political ideology."

"These questions and opportunities align well with the collective expertise of the SFI research network in machine inference, environmental science, research policy, financial markets, and complexity education," adds Krakauer. "By convening thoughtful data scientists with complexity scientists spanning a range of disciplines, we aim to foster conversations and research efforts that integrate their approaches in new and useful ways."

## SFI ON THE arXiv

# Innovative pre-prints and unpublished research

### Progress toward solving a stubborn problem

In recent work, a team of researchers including SFI Omidyar Fellow Joshua Grochow used the tools of algebraic complexity theory to chip away at what's widely considered to be one of the most challenging open problems in mathematics.

"P versus NP" asks whether problems with solutions that can be quickly verified ("NP" problems) can also be quickly found by a computer algorithm ("P" problems).

Often in math, finding what won't work opens up new insights. In their work, Grochow and his collaborators showed that certain techniques from algebraic complexity theory probably won't work against the "counting" analog for P versus NP.

Grochow says solving the "counting" version won't solve P versus NP, but it is "an important milestone on the way."

"Towards an algebraic natural proofs barrier via polynomial identity testing" by Joshua A. Grochow, Mrinal Kumar, Michael Saks, and Shubhangi Saraf is available on the pre-print server arXiv.org.


*Can one follow a path through a graph that touches each node once and only once, ending where it began? This Hamiltonian game illustrates an important distinction in the P vs. NP problem: whether finding the right path (P) is the same as recognizing the right path after it has been found (NP). (Image: Royal Irish Academy)*

### A well-timed glitch

Three theoretical astrophysicists, including SFI's co-founder David Pines, teamed up with a radio astronomer to develop a better way to predict the arrival of a "glitch:"  a sudden spin-up in the rotation rate of a carefully observed neutron star.

On December 12, 2016, as the authors were submitting their theory for publication and posting it to the arXiv server, they received word of  an astronomer's telegram. Their neutron star, the Vela pulsar, which has been observed to glitch every three years or so for the past 50 years, had just glitched again. The observation of the new glitch confirmed the accuracy of the team's prediction to within some 100 days.

According to Pines, the roughly 10 percent margin of error constitutes "a much better forecast for a catastrophic event, the simultaneous unpinning of superfluid vortices in the crust of a faraway neutron star, than we can do with quakes here on Earth."

The paper expands on the authors' detailed model of vortex pinning and creep in pulsars, developed between 1984 and 1993; in addition to its ability to predict the fortuitous December glitch, their new model provides a good fit to the interglitch data on eight recent observed glitches of the Vela pulsar. It also improves the fit to the earlier glitches and allows for an accurate estimate of the pulsar's breaking index.

"Nonlinear interglitch dynamics, the braking index of the Vela pulsar and the time to the next glitch" by Onur Akbal, M. Ali Alpar, Sarah Buchner, and David Pines is available on arXiv.org.

# SFI names Paul Hooper Director of Education

SFI has named evolutionary anthropologist Paul Hooper as its new Director of Education.

Hooper, a former Omidyar Fellow, joined SFI's education office January 30, 2017 to produce and direct the Institute's iconic summer schools, mentorships, courses, and online educational resources.

"I am simply thrilled to lead SFI's educational mission to bring the best of complexity science to the world," Hooper says.

Hooper's research centers on the co-evolution of human economic systems, demography, and social structure. During his Omidyar Fellowship from 2012 to 2014, he traveled to Bolivian Amazonia twice a year to study health and social support among the Tsimane forager-farmers, returning to SFI to mathematically model the social structures he observed.

In his new role at the Institute, he's eager to introduce the next generation of complexity scholars to some of the tools and concepts that advanced his own research.

"We are all very enthusiastic that Paul has agreed to join SFI and direct education," says President David Krakauer. "Paul has a unique combination of educational experience, complexity knowhow, creative ideas about new forms of educational activity and outreach, and the trained anthropologist's eye and skills for navigating through what is surely one of culture's more complex institutional structures — the educational system."

Before re-joining the Institute in his new role, Hooper was an assistant professor of anthropology at Emory University in Atlanta, Georgia. He holds a Ph.D. in evolutionary anthropology from the University of New Mexico, and earned his A.B. in near eastern studies from Princeton University.

**Y2K bug** *(cont. from page 1)*

The group has a couple of robust datasets (by ecology standards) to work with, thanks to the longstanding interest in cicada behavior and "precision agriculture"methods applied to thousands of pistachio trees.

Among the more intriguing phenomena up for inquiry are local drivers like root grafting or soil temperature and global drivers like major weather events, what happens when both kinds of effects are at play, and how to go about disentangling them.

**Toby Shannan** *(cont. from page 2)*

him to present at an upcoming ACtioN meeting in Austin, TX.

"This is exactly the kind of insight we want our members to bring to us," Tracy says. "Toby saw something in his everyday life that had some clear connections to complexity, and this was a chance to share it with our community.

At the Austin meeting, Shannan's talk was paired with one by SFI External Professor Simon DeDeo in a marbling of scientific and business concepts, says Tracy. DeDeo presented recent social science research, inspired by information theory, that quantifies how people interact with novelty and how they choose to adopt or reject something new, DeDeo says.

Shannan says he "found a lot of open-minded people" at the meeting who were genuinely interested in shared problems in science and business. "It was a chance to think more deeply about the problem with people who know a lot more about complexity," he says.

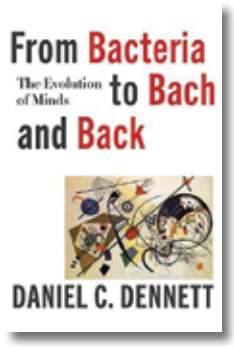
It's also inspired him to ponder the vocabulary of complexity.

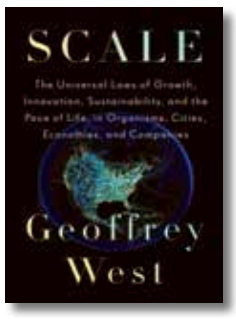
"I guess initially I kind of fell under the spell of complexity as a catchall for the problems we had a Shopify," he says. "As I read some of the scientific papers and gained a more technical understanding of the science, I began to make more tangible connections."

"It occurred to me that the interdisciplinary nature of complexity science extends to business," he says. "That's not true for most of science. The vocabulary of complex systems will be quite useful in the world of businesses as it deals with increasingly rapid change. It's absolutely going to happen."

# New books by SFI authors

***From Bacteria to Bach and Back: The Evolution of Minds*** (Norton, 2017) by SFI External Professor Daniel Dennett delves into the mystery of why we have minds, and how they emerged from a material process of natural selection. Drawing on concepts from computer science and biology, Dennett depicts how the human act of sharing memes yields tools for acting outside of genetic instinct. Competition between these memes, and the process of exchanging them, can create a cultural evolutionary process that forms our creative and comprehending minds.




***Scale: The Universal Laws of Growth, Innovation, Sustainability, and the Pace of Life in Organisms, Cities, Economies, and Companies*** (Penguin Group, 2017) by Distinguished Professor Geoffrey West tells of the astonishing mathematical regularity that underlies complex life. West's "theory of enormous power" explains why cities live forever, why businesses die, and why heartbeats circumscribe lifespans for mice and men alike.


***43 Visions for Complexity*** (World Scientific, 2017) edited by External Professor Stefan Thurner collects visions for complexity science in the next decade, in the form of short essays by acclaimed scientists and thinkers. Many SFI faculty contributed to the volume, taking up topics such as "society's major challenges" and "the data-driven dark ages." It is the third volume in a series dedicated to exploring complexity.

# Better together? Working group seeks principles of collective behavior

In biological systems, function emerges from interactions among semi-independent components. An example is the brain — a huge society of neurons capable of producing coherent, robust behavior at the whole organism level. Another example is a group of fish that can switch quickly between a loose spatial configuration ideal for foraging to a tight group formation ideal for escaping predators. A theory for how individual components come together to produce functionally useful patterns at the aggregate level remains elusive.

A first question we might ask is: How collective is the system? Is the system reducible to its parts, or do components come to depend on each other to such an extent that they cannot be considered independently of each other? And, similarly, is a functional pattern at the aggregate level highly sensitive to small changes in components' behaviors, or is it relatively impervious to perturbations?

These and similar questions will be the focus of a working group, "Quantifying Collective Behavior in Living Systems," being held at the Santa Fe Institute May 3-5. The working group is organized by ASU-SFI researcher Bryan Daniels, ASU Professor and SFI External Professor Manfred Laubichler, and SFI Professor Jessica Flack.

"The goal of the working group is to ask whether there are common principles of collective behavior across a diverse set of systems," said Daniels. "How do groups maintain stable, robust behavior at the aggregate level but stay adaptable such that they can change when the environment requires it? Are there quantitative ways we can measure this across different systems?"

The hope is that sharing ideas in the working group might allow for a common language for researchers studying collective information processing in multiple disciplines. A mutual area of interest involves finding tipping points — being able to quantify and explain what events cause a system to switch between functional states at the aggregate level or to move from being in exploitative and robust mode to an exploratory and adaptable mode.

In addition to understanding how fish switch as a group between schooling and foraging, unifying principles of collective behavior might help explain apparently large shifts in political view points in elections or how societies that seem so democratic can suddenly show signs of authoritarianism.

"How that unfolds is very much the kind of question we're interested in," said Daniels. "Maybe the political decision-making process looks similar to how neurons make decisions in the brain or how fish school."

*Collective behavior can help animals like sardines navigate during migration, find foraging ground, and avoid predators. A May working group will look for unifying principles in collective behavior across diverse systems.*

## RESEARCH NEWS BRIEFS

*A woman lights an oil lamp to celebrate Deepavali, the Hindu festival of lights. (Image: Eleanor Power)*

### RELIGIOUS PRACTICE MAY STRENGTHEN SOCIAL BONDS

Roughly 80 percent of people around the globe identify with some type of religion, and scientists have been seriously pursuing insight into the evolutionary benefit of religious belief and practice since the early part of this century. In a paper published in *Nature Human Behavior,* Omidyar Fellow **Eleanor Power** shares her analysis of religious practice and social support networks in two villages in South India. Power finds that active religious participation may benefit practitioners by strengthening social bonds.

### MAKING SENSE OF MICROBIOMES

We know that human health is intricately tied to the microbes living in and on our bodies. Imbalances in our microbiomes can lead to conditions including obesity, type 2 diabetes, cancer, and autoimmune diseases. But we still don't know which of the hundreds of thousands of microbial species are responsible for which diseases. A new model, described in a paper in *Cell Host & Microbe*, integrates functional and taxonomic approaches to profile the microbiome. SFI External Professor **Elhanan Borenstein** and colleagues used the model, called FishTaco, to study two types of diseases, identifying combinations of bacterial species that contribute to functional imbalances.

### TO BETTER UNDERSTAND ANIMALS, TRY HUMAN LANGUAGE RESEARCH

Animals can adjust their communication based on their audience, but scientists have only a basic understanding of how they do so. A paper published in the journal *Animal Behavior* calls for further study of this "audience effect" across (non-human) animal species, by going beyond simple behavioral metrics and instead analyzing animal signals using methods similar to those used in human language research. ASU-SFI fellow **Elizabeth Hobson** co-authored the paper with Brittany Coppinger, the lead author and Hobson's mentee.

### COLLECTIVE BEHAVIOR ENDANGERS BISON

Collective decision-making can be beneficial for social animal groups, but not if members have bad information, suggests a new study co-authored by Omidyar Fellow **Andrew Berdahl** in *Ecology Letters.* When part of a herd of bison found prime grazing land on a farm beyond the border of Canada's Prince Albert National Park where they lived, others followed. The exposure to hunting led to a 12 percent annual adult mortality, showing that just one individual can be the agent of bad information for many in a fusion-fission society.

### INFORMATION AS ENGINE FUEL

In a paper published in *Physical Review E,* External Professor **Jim Crutchfield** and colleagues describe an engine that runs on information. "Information is a thermodynamic fuel," they write. "And we can build engines that run on it." How the engine synchronizes with its environment is key to their design, which uses correlational information to convert "disorganized thermal energy to useful work."

### CHEMICAL REACTION BREEDS LIFELIKE BEHAVIORS

Creating a life-like system from non-living components is a central pursuit in the field of synthetic biology. In research published in *Nature Scientific Reports*, External Professor **Juan Pérez-Mercader** and colleagues describe creating a synthetic reaction out of a homogeneous chemical "soup." The vesicles that result display several emergent properties associated with life: they appear to grow, self-replicate, move toward a light source, and experience selection.

### A MACROSCOPIC VIEW OF CANCER

The vast majority of cancer research focuses on how tumors form in cell cultures and special strains of laboratory mice. But cancer is a larger-scale phenomenon. The complexity of how evolution and environments interact to produce cancer risk is the subject of a new study published in *Ecology Letters*, authored by External Professor **Michael Hochberg** and a colleague. Their macroscopic framework for cancer risk considers three interacting causes: the number of stem cell divisions in a body, changes in cellular function, and heritable transformations to the cancer phenotype.

### SEARCH SMARTER NOT HARDER

If an engineer drilling for oil or an animal foraging for food searches and doesn't find what they're looking for, when should they abandon their search area and strike out for new territory? In a study published in *Physical Review E*, SFI Professor **Sidney Redner** and colleagues propose an optimal search strategy. Using a model that respects two opposite actions — moving on immediately when the search turns up empty versus remaining in one area indefinitely — the team says the best strategy is remain in one area for a time that equals the time it would take to re-establish in a new territory.

### LIFE'S LOWER LIMITS

What are the lowest energetic limits for life? In a study published in *Frontiers in Microbiology*, SFI's **Chris Kempes**, **Eric Libby**, and **David Wolpert** analyze cellular processes and maintenance budgets across sizes and species of bacteria. They find a surprisingly constant maintenance cost per unit volume, with the smallest cells devoting almost all of their energy to protein repair and very little to replication. The authors' ongoing investigation could help us understand ecological constraints on other planetary bodies in our solar system, as well as on our own.

> MORE ON PAGE 6

## RESEARCH NEWS BRIEFS

*(cont. from page 5)*

### SHOULD THE 'SCIENCE OF SCIENCE' STEER FUTURE RESEARCH?

In the age of big data, a new field of science has emerged: the science of science. SFI's External Professor **Aaron Clauset**, Omidyar Fellow **Dan Larremore**, and Roberta Sinatra of Central European University wonder if today's data on science can predict future discoveries. If so, existing bibliographic databases like Google Scholar, Web of Science and PubMed could provide scientists and funding organizations with useful information. But using these publishing trends to direct future research could create problematic feedback loops and limit unexpected discovery. The essay appeared in *Science*.

### CERAMICS REVEAL ANCIENT SOCIAL STRUCTURES

In a study published in *Ecology and Society*, External Professor and Past President **Jeremy Sabloff** and colleagues look at cities in the Maya lowlands, tracing patterns of trade and networking, and changes in decision-making practices in relation to ecosystem health over the span of about 3,000 years. An early period when interior cities thrived show signs of ecological decline, while a later period when coastal cities held more influence appears more ecologically sustainable. Understanding the impact these cities, networks and decision-making patterns had on their ecosystems could be useful for modern decision-making on the global scale.

### MONKEY FIGHTS HELP EXPLAIN SOCIAL TIPPING POINTS

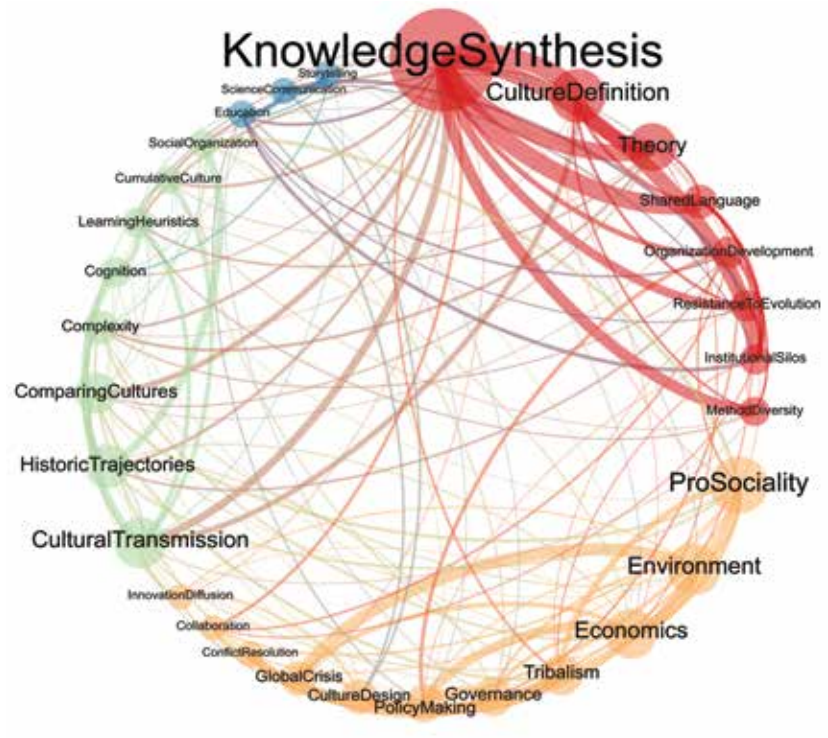
Previous studies suggest that animal societies may approach "critical" points where groups are extremely sensitive and can be easily tipped into new social regimes. But how far animal societies sit from that critical point, and what controls that distance, remain unknown. **Bryan Daniels** (ASU-SFI Center for Biosocial Complex Systems) along with SFI's President **David Krakauer** and Professor **Jessica Flack** analyzed conflicts within a captive community of pigtail macaque monkeys to help to answer these questions. Using ideas and models from statistical mechanics, they show how the interplay of group sensitivity and individual members' behavior determines the distance to the critical point. Their study appeared in *Nature Communications*.

### GAMING CYBER ATTACKERS

Victims of cyber attacks should think twice before responding, according to a recent paper in *Proceedings of the National Academy of Sciences* co-authored by External Professor **Stephanie Forrest**. Her group's game-theoretic model shows when a nation should quietly tolerate an attack and when it should respond by publicly shaming the attackers. The model applies to a wide range of conflicts and provides guidance to policymakers about factors to consider prior to assigning attribution and blame.

### CITIES SHOW METABOLIC RIFT WITH NATURE

All populations of species in any given environment average roughly the same energy flux. That's why an environment will have few big animals, which need a lot of energy to survive, and many smaller organisms with lower energy requirements. Historically, humans had smaller densities than other animals our size. But fossil fuels have allowed humans to supplement our energy and materials. A paper developed during SFI's **Complex Systems Summer School** in Chile, published in *Nature Scientific Reports*, finds that most modern humans now live in densities four orders of magnitude greater than hunter-gatherers and consume significantly more energy.




*Frequency and co-occurrences of themes identified in survey responses to the grand challenges for cultural evolution. Node (theme) size is scaled to the number of times each appeared in the pool of grand challenge ideas; edges (co-occurrences) are scaled to the number of times any two themes appeared in a given nomination. (Image credit: Ian MacDonald, Nature Publishing Group)*

### GRAND CHALLENGES FOR STUDY OF CULTURAL EVOLUTION

The scientific study of culture is currently going through a theoretical synthesis similar to what the field of biology experienced in the 20th century, write External Professor **Peter Peregrine** and colleagues in a paper published in *Nature Ecology and Evolution*. Darwinian principles will soon be applied as consistently to the study of culture as they are to that of biology, the paper hints. But what do researchers view as the biggest scientific questions facing the field? A survey of 236 Cultural Evolution Society members returned 422 different "grand challenge" ideas, revealing five major themes. These include knowledge synthesis, culture definition, pro-sociality, environment, and cultural transmission.

### WHAT'S CUING SALMON MIGRATION PATTERNS?

Why salmon move in pulses is the subject of a new paper published in *Animal Behaviour*. Authors **Andrew Berdahl** and colleagues question the folk wisdom that sockeye salmon in southwest Alaska are independently cuing off common environmental triggers when they migrate in pulse-like groups. Instead, the authors present a model based on social cues, which reproduces the timing and migration patterns observed in real fish.

## UPCOMING COMMUNITY EVENTS

### *Caught in the Pulpit: Exploring the Journey from Religion to Reason*, a play by Marin Gazzaniga based on the book by Daniel C. Dennett and Linda LaScola, Tuesday, May 9, 7:30 p.m., The Lensic Performing Arts Center

What does it mean to struggle with the idea that there is no God when your life has been devoted to preaching that there is? This is the quandary clergy find themselves in when they go from believer to atheist while they are on the job. Marin Gazzaniga's play — based on interviews of clergy by Linda LaScola for a Tufts University study she conducted with Daniel C. Dennett — explores the mental anguish and struggles of seven clergy, interviewed privately in hotel rooms around the country, as they reveal personal feelings they've never shared. The audience is led on an intimate psychological journey as these individuals struggle with a taboo subject: what's at stake if you publicly say you don't believe in God. In hearing their stories, we are challenged to re-examine deeply help assumptions about religion and belief.

In this special event, part of SFI's 2017 Community Lecture Series, actors will present select scenes from Gazzaniga's play, followed by discussion with cognitive scientist and philosopher Dennett (an SFI external professor) and Michael S. Gazzaniga, a cognitive neuroscientist (and the playwright's father), about what brain-mind mechanisms might be at work in religious belief — and the implications for individuals and society.

### Interplanetary Project: Stage One, A Panel Discussion, Tuesday, July 18, 7:30 p.m., The Lensic Performing Arts Center

The first phase of SFI's InterPlanetary Project brings together science fiction authors, scientists, explorers, and private companies for a panel discussion about the challenges of space exploration.

What will it take to become an InterPlanetary civilization? How should we address the most pressing problems of Earth to tackle a challenge at this scale? What will success mean for future generations? What is holding humanity back and what do we all need to achieve in terms of novel governance, new technologies, shared resources, and global cooperation to achieve this goal?

Equal parts conference, festival, and research program, the InterPlanetary Project combines celebration with experimentation, and conversation with analysis. Confronting the challenges of space requires braving and solving the complexities of life. InterPlanetary aims to ignite a whole-planet project — beyond borders, beyond politics, beyond economics — to activate the collective intelligence on our first planet: Earth.

*SFI's 2017 Community Lectures are made possible through the generous underwriting of Thornburg Investment Management, with additional support from The Lensic Performing Arts Center. Tickets for this event are free, but reservations are required; to reserve tickets, visit http://tickets.ticketssantafe.org. Watch lectures live on SFI's YouTube page.*

Parallax
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