Winship named Director for Advancement

SFI welcomes Shelley Winship as its new Director for Advancement. A New Mexico resident for the past 13 years, Winship has forged positive donor relationships across the U.S. for two of the region's most prominent performing arts organizations: The Santa Fe Opera, as Major Gifts Officer and Manager of Planned Giving; and the Santa Fe Chamber Music Festival, as their Director of Development.

In her prior home state of Oregon, she served as Director of Development for a large regional food bank before joining the Institutional Advancement team at the University of Oregon — first as Assistant Director of its Annual Giving Program, then as Director of Development for its School of Architecture and Allied Arts during the first three years of an $850 million, university-wide comprehensive campaign.

To individuals contemplating a gift to SFI, Winship has this to say: "Giving the great minds at SFI the time, resources, and freedom to pursue today's 'big questions' has proven again and again to yield insights that impact our lives, and our world, for the better. So while the science itself is complex, the reasons for supporting SFI's unique brand of collaborative research couldn't be simpler."

UPCOMING COMMUNITY EVENTS

Energy and matter at the origin of life: SFI Community Lecture, Nick Lane, Tuesday, November 7, 7:30 p.m., The Lensic Performing Arts Center

All living things are made of cells, and all cells are powered by electrochemical charges across thin lipid membranes — the "proton motive force." We know how these electrical charges are generated by protein machines at virtually atomic resolution, but we know very little about how membrane bioenergetics first arose. By tracking back cellular evolution to the last universal common ancestor and beyond, scientist Nick Lane argues that geologically sustained electrochemical charges across semiconducting barriers were central to both energy flow and the formation of new organic matter — growth — at the very origin of life.

Lane is a professor of evolutionary biochemistry in the Department of Genetics, Evolution and Environment at University College London (UCL). His research focuses on how energy flow constrains evolution from the origin of life to the traits of complex multicellular organisms. He is a co-director of the new Centre for Life's Origins and Evolution (CLOE) at UCL, and author of four celebrated books on life's origins and evolution. His work has been recognized by the Biochemical Society Award in 2015 and the Royal Society Michael Faraday Prize in 2016.

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
Fall 2017
THE NEWSLETTER OF THE SANTA FE INSTITUTE

1399 Hyde Park Road
Santa Fe, New Mexico 87501
505.984.8800
www.santafe.edu

RESEARCH NEWS BRIEFS

(cont. from page 5)

WHAT ALGAE CAN TELL US ABOUT POLITICAL STRATEGY

Cells compete for nutrients. Political campaigns compete for voters. According to new research published in *Nature Scientific Reports*, general principles may begin to explain how differing strategies play out where groups compete for resources. SFI Omidyar Fellow Eric Libby and SFI Research Fellow Laurent Hébert-Dufresne wondered if understanding how algae evolve differing complex life cycles could help explain dynamics in voter populations. They found that when two competing ideologies squared off with offensive strategies, both parties would persist. When both were more defensive, the less defensive group disappeared entirely. But when a third party was added to the mix, the winning strategy used a level of offense higher than one opponent but lower than the other.

WHY DO PERU'S PARROTS EAT CLAY?

Amazonian Parrots in southeastern Peru gather along the clay banks of the Tambopata River to scoop up beakfuls of soil. It's a confounding behavior — clay soil has no proteins or carbohydrates. Researchers have tossed around two leading theories about what drives this geophagy: that clay helps protect the birds from dietary toxins, or it's a nutritional supplement. In a paper published in *Ibis*, ASU-SFI Center Postdoctoral Fellow Elizabeth Hobson and co-author Donald Brightsmith (University of Texas Austin) analyzed data logged from more than 20,000 hours of observation on the Tambopata — one of the most extensive datasets on tropical parrots ever gathered — adding evidence to the supplement theory, joining a large body of research suggesting that hunger for sodium, specifically, is that driver.

SEEING IN THE DARK: MINUS SUNLIGHT, A GENERAL THEORY REVEALS UNIVERSAL PATTERNS IN ECOLOGY

In a recent paper published in *Global Ecology and Biogeography*, SFI External Professor John Harte (University of California Berkeley), SFI Omidyar Fellow Andy Rominger, and Erica Newman (University of Arizona) suggest that a theory independent of mechanistic drivers, such as sunlight, can accurately describe the distribution of species in a forest. Drawing on Harte's maximum entropy theory of ecology, the team re-analyzed data from a 2016 study that included light-limitation parameters, deriving nearly identical patterns. The team hopes their work will help open broader discussions about the benefits of using simpler models to understand universal patterns in ecology.

HAYEK'S MARKET ALGORITHM IS NOT THE ROAD TO LAISSEZ FAIRE

In a fresh look at 20th-century philosopher-economist Friedrich Hayek, three authors note how the Nobel laureate's work exemplifies complexity economics. They also show how his political support of laissez faire economic policies needn't necessarily follow. Hayek was among the first to view the perpetually adaptive nature of an economy as counterpoint to the notion of equilibrium. His work led him to embrace laissez faire policies. But these policies can lead to bubbles and crashes. "It is possible to appreciate [Hayek's] insights into the functioning of a market economy without following him down the road to laissez faire," write authors Alan Kirman (University of Aix-Marseille), SFI Professor Samuel Bowles, and SFI External Professor Rajiv Sethi (Columbia University), who published their paper in the American Economic Association's *Journal of Economic Perspectives*.

BIRDS CHOOSE MATES WITH ORNAMENTAL TRAITS

A recurring theme in nature documentaries is that of choosy females selecting brightly colored males. But in monogamous mating systems, male birds may select their lifelong mates in much the same way, finds a new study published in Ecology and Evolution by SFI Research Fellow Caitlin Stern. Some traits, such as the tuft of feathers atop a crested auklet, signal attractiveness to the other sex and competitive rank within the same sex. Research has traditionally focused on male competition for access to females or territory and on females choosing males based on their feathers and fights. But recent investigations suggest that females not only compete with each other, but also rely on such traits in deciding whether to engage or defer.

THE ROLE OF COLLECTIVE MEMORY IN PRIMATE CONFLICT

In new paper in the *Journal of the Royal Society Interface*, The Collective Computation Group @SFI (C4) explores the role of collective memory in managing length and severity of fights between primates. While studying the dynamics of conflict in a primate society, researchers Edward Lee (Cornell University), ASU-SFI Center Postdoctoral Fellow Bryan Daniels, SFI President David Krakauer, and SFI Professor Jessica Flack found evidence that suggests it is not the number of individuals who control the length of fights (as in a contagion model), but the relationships between pairs of individuals. Because statistical variation in the observed fights strongly suggests that conflict duration is set by the first interaction, the researchers propose that "The duration of the conflict is not just determined by individuals independently deciding whether to continue fighting or drop out, but through their joint memory for the past and subsequent collective decision-making."

THE EVOLUTION OF RISK PREFERENCES

A new study by SFI Research Fellow Caitlin Stern and Oren Kolodny (Stanford University) explores the domains in which animals might evolve to be more or less risk averse. Through an agent-based simulation they explored how factors like inter-generational reproductive dynamics, life history, and population size determine whether an animal chooses a behavioral strategy that is risky or risk-averse. Across species, individuals must frequently decide between strategies that carry more or less risk; for example, predators decide to pursue prey that are small and ubiquitous, or large, but difficult-to-catch. Understanding how selection acts on risk preference is "crucial to interpreting and predicting behavior," according to the researchers. Their paper, "Evolution of risk preference is determined by reproduction dynamics, life history, and population size," is published in *Nature Scientific Reports*.

PERSONALITY TRAITS CORRELATE WITH SOCIAL NETWORK POSITIONS

A new network analysis by SFI External Professor Matthew Jackson (Stanford University) and colleagues corroborates findings from psychological research: students turn to one set of friends when they're looking for shared fun and excitement, but a different set when they need empathy. The analysis, published in *PNAS*, drew from questionnaires and personality tests administered to nearly 200 Stanford freshmen. It showed that different students occupy central roles in networks based on fun and excitement versus networks based on trust, suggesting that "individuals' traits are related to their network positions and to the different roles that they play in supporting their communities."

BACTERIA COMPETE TO SHAPE YOUR MICROBIOME

A new paper by SFI External Professor Elhanan Borenstein (University of Washington) and colleagues shows that competitive interactions between bacterial species play an important role in shaping the composition of the human gut microbiome. The researchers used metagenomic analysis to map the landscape of toxin and immunity factors from the type VI secretion system — a pathway that mediates interbacterial competition — in the gut microbiome. Examining this landscape and the presence of different bacterial strains in adult and infant microbiomes, they find evidence that competition between different gut bacterial strains may determine which strains will stick around and which may be competed away. The paper, published in *Cell Host and Microbe*, is part of Borenstein's ongoing work to understand systems-level dynamics of the human microbiome.

Fall 2017

Parallax

THE NEWSLETTER OF THE SANTA FE INSTITUTE

Casting a wide net

Working group examines human-centered interaction networks through space and time

Humans have used the plants and animals in their ecosystems in myriad ways: we've eaten them, but we've also used them for clothing, tools, landscaping, and more. A group of ecologists, anthropologists, and archaeologists studying pre- and non-industrial human communities in places around the world are working to compile, analyze, and model data about these many types of interactions to see how they vary or stay the same across cultures, ecologies, and environments over time.

The group, which met for the first time last February, gathers again November 6-8. This second meeting will include an additional study site, expanding the scope from five to six regional locations.

"We're asking really outstanding researchers with deep expertise in their fields to compile new kinds of data that have never been collected before," says SFI Vice President for Science Jennifer Dunne. "It's exciting to bring everyone together and see opportunities for new kinds of questions to be asked and new hypotheses to be tested. This is a novel research frontier."

Since February, the working group members have begun compiling and analyzing a wide range of data. Some existing datasets have focused on feeding interactions, like Stefani Crabtree's recent analysis of ancient Puebloan food webs in the southwestern U.S. Some have focused more on other types of interactions, often in very species-specific ways. "For instance, in the Pacific northwest, ethnographers have spent entire careers studying one thousand and one uses for red cedar bark by First Nations people in Canada," says Dunne. This project means collating scattered data sets, often ones that have never been digitized, and combining them with other data sets for more comprehensive, quantitative, big-picture analyses.

Dunne hopes that exploring both simple interactions — like a human gathering a mussel from the water, breaking it open and eating it raw — and complex interactions that require multiple species and types of interactions — like a human building a kayak out of wood, hide, and gut and using a bone-tipped wooden spear to hunt and eat sea lions — could provide a "biodiversity-focused" way to understand the dynamics of human technology use and innovation across time and in relation to ecology, climate, and culture.

SFI launches in-house press

If you search for "complexity" on a university press website, you'll turn up a dozen or so intriguing book titles priced at a median of $49 for paperback, $99.50 for hardcover.

"The notoriously high price of scholarly books belies their primary purpose — to disseminate knowledge," says SFI President David Krakauer. "It's driven academics to read only the volumes they can borrow through their institutional libraries and the wider readership to ignore these writings altogether."

In order to make SFI scholarship accessible to a wider audience, Krakauer decided last January to launch the SFI Press. He's envisioned the in-house publishing service as a locus where the best work in complexity science — spanning new and archival SFI-related research — materializes as books that travel quickly through the publication process and cost far less to buy than comparable university press-published SFI volumes.

The SFI Press' publishing strategy involves releasing titles as e-books and print-on-demand paperbacks that will cost below $5 and below $10, respectively, and can be ordered through Amazon.com.

The Press' book list debuted with the publication on Apr. 15 of *History, Big History, and Metahistory* editors: SFI President David Krakauer, John Lewis Gaddis (Yale), and Kenneth Pomeranz (University of California Irvine)). The e-book, released in October, is now available through Amazon and iBooks. On deck is *The Emergence of Archaic States: New Perspectives on the Development of Complex Societies* (editors: SFI External Professor and Past President Jeremy A. Sabloff and SFI External Professor Paula L.W. Sabloff).

The Press accepts anthologies, papers, monographs, and proceedings of meetings not published before, and is also establishing permissions to re-publish seminal complexity science texts previously published by Addison-Wesley and Oxford University Press.

Jeremy Sabloff says the launch of the press "makes eminent sense." His research group's forthcoming anthology will include eight

> MORE ON PAGE 4

What are the limits of scientific understanding?

This is the query that will drive a three-day workshop at SFI, which itself aims to understand how well scientific and mathematical reasoning can comprehend complex systems.

"When we went to school and we put down the answer to a question, we always had to explain how we'd gotten there," says SFI President David Krakauer, one of the workshop's co-organizers. "There was always a concern that we'd cheated or stumbled on the right answer." With recent advances in machine learning, however, Krakauer says we have no easy way of evaluating the problem-solving process. "Machines are terrible at explaining things. We're now living in an age where we're confronted with significant limits in understanding. With artificial intelligence, the open question is 'will the limits to our understanding ever be transcended by technologies or will technologies make understanding irrelevant?'"

The workshop was conceived by Krakauer, SFI and MIT Postdoctoral Fellow Brendan Tracey, and former SFI Omidyar Fellow Joshua Grochow (University of Colorado). It is designed to address a recurring challenge at the heart of complexity research: if complex systems are not amenable to the classic model of scientific explanation, on what basis does complexity research grant us scientific understanding?

The question arises because complexity researchers often rely on methods and computational tools that do not provide both predictive and explanatory power — two criteria for scientific understanding essential to the classic model of scientific explanation. A computational model that offers sound predictions and new insight into large-scale patterns, for example, may not help us arrive at an exacting phenomenological explanation.

According to Tracey, "we are in an age where we see much greater conflict between understanding and prediction." Scientists find themselves asking: if a machine learning tool gives us predictive power but we don't understand why it generates accurate predictions, do we have scientific understanding? Is research that relies on a black box properly called science?

A central goal of the workshop will be to establish a clear definition of scientific understanding

> MORE ON PAGE 5

BEYOND BORDERS

From the perspective of complexity theory many of our scientific challenges can be viewed as problems of sociality. Complex systems are adaptive many-body systems — social systems — spanning the society of cells to the society called a civilization. These all need to reckon with uneven distributions of resources and power, imperfect knowledge, structured interactions (networks), challenges of inference, and misaligned strategic objectives. Hence the distinctions between the natural and the social sciences as conventionally practiced have largely been distinctions of material and origin (see departments) and not distinctions of mechanism and function (see reality). Intellectual commerce among Malthus, Smith, Darwin, Marx, and Hayek should provide sufficient historical precedent of this porosity.

For this simple reason SFI has paid scant attention to heated debates around the divisions of natural and social science and has sought to transcend them, or at least encourage efforts at conjugation, through the more inclusive label of complexity science.

One can ask, however — indeed is more or less required to ask — how the broad church of complexity science has contributed to the creeds of the disciplines: in what ways insights from academic syncretism flows back to advance the dominant concerns of its varieties.

With this intention Jessica Flack and I recently hosted a two-day meeting at SFI with a group of our long-term affiliated researchers (see list on page 4) with the purpose of reviewing the several areas in which complexity science has advanced toward solutions in problems of sociality. Below is a very brief list of those areas where these advance are convincing.

New dynamical theories of institutions and institutional change — from the rise and fall of companies, regime change in government, to the impacts of social movements.

The infectious propagation of beliefs and their structural correspondence to the transmission of disease and the impact of network structures on transmission.

The principled inclusion of cognitive data in social models to include errors of judgment, bias, and fear in agent-based models of society and the economy.

The extension of game theory to deal effectively with multi-actor, multiple-time scale events and placing these theories within a sound inductive framework.

Advances in the theory of collective computation that explore the collective, memories and inferential properties of groups.

The potential of new technological and online data sets (advancing far beyond surveys) — from Facebook to Wikipedia to the Connectome Project — to generate new models for large-scale social behavior.

The application of the principles of scaling to analyze the rigorous correspondences among biological, social and technological systems.

In 1986, two years following the establishment of the Santa Fe Institute, we hosted meetings on topics that included: International Capital Flows as a Complex System, Heterogeneity and Public Policy, Economics — Foraging and Range Management, and Dynamical Stability in International Security Affairs. Interspersed with these were meetings on: Structure, Dynamics and Functions of Proteins, Mechanisms of Gene Expression, and Aspects of Self-Similarity and Scaling. From the start we have been searching for portals that might connect the dimensions of complexity. In this recent meeting we discovered that we have traveled further than even a millennial optimist might have had a right to expect.

— David Krakauer
President, Santa Fe Institute

CREDITS

EDITOR: Jenna Marshall
CONTRIBUTORS: Ellen Berkovitch, Joseph Brownstein, Natalie Elliot, Lucy Fleming, John German, Andrea Jones-Rooy, Aaron Leventman, Katherine Mast, Stephen Ornes, Deb Trevino, Krista Zala
DESIGN & PRODUCTION: Laura Egley Taylor & Talaya White
VP FOR SCIENCE: Jennifer Dunne

Parallax is published quarterly by the Santa Fe Institute. Please send comments or questions to Jenna Marshall at marshall@santafe.edu.

SFI IN THE NEWS

With the September publication of their introductory economics textbook, the **Curriculum Open-access Resources for Economics (CORE)** project received glowing reviews in *The Economist, The New Yorker, The Independent,* and other major media outlets. (See "Books" on page 5)

ASU-SFI Postdoctoral Fellow **Elizabeth Hobson** was quoted in *Forbes* on Aug. 9 and in a National Public Radio blog on Sept. 7 for her recent work which builds on a large body of evidence suggesting that the need for sodium is what drives Amazonian parrots to eat clay. (See "Research News Briefs" on page 6)

Science, on Aug. 9, featured new research by SFI External Professors **Scott Ortman** and **Tim Kohler** (also a member of SFI's Science Board), which looks to DNA from turkey bones for clues as to where Ancestral Puebloans went after abandoning their settlements.

In *Nautilus* on Aug. 3, SFI's Vice President for Science **Jennifer Dunne** commented on modern ecologists' approach to studying dynamic, complex systems in ecology.

In an article published Aug. 1 in *Forbes*, SFI President **David Krakauer** talked with columnist **Robert Wolcott** about how the human experience might continue to change with advancing technologies.

In July, **Bill Miller**, Chairman Emeritus of SFI's Board of Trustees, was featured in *The Wall Street Journal* and in *Forbes* for winning the Journal's quarterly stock-picking contest. His Miller Opportunity Trust (LMOPX), which he manages with CFA **Samantha McLemore**, gained 48.55% over 12 months, beating its closest rival by nearly six percentage points.

The Atlantic, on July 11, featured SFI Professor **Jessica Flack's** research on biological collectives in an article titled: "The Countless Computers Embedded in Nature." The article about Flack's work with **The Collective Computation Group @SFI (C4)** originally appeared in *Quanta*.

Scale: The Universal Laws of Growth, Innovation, Sustainability, and the Pace of Life in Organisms, Cities, Economies, and Companies was reviewed in *Science, The New Yorker,* and in *Bloomberg Businessweek*. Author **Geoffrey West**, SFI Distinguished Professor and Past President, was also interviewed on the "Waking Up" podcast, the "Hidden Forces" podcast, and KSFR radio.

SFI Miller Scholar **Sam Shepard**, a legendary playwright and actor, was remembered on the BBC and in *The New York Times, Nautilus, The Santa Fe New Mexican, The Santa Fe Reporter,* and *The Albuquerque Journal* after his passing on July 27 at the age of 73.

Life is short, evolution is long: Working group tackles temporal challenge

There's a longstanding challenge in biodiversity research: how can we better understand the interplay between ecological processes — things like birth, death, and migration — and evolutionary processes like speciation, extinction and long-distance dispersal? Researchers know that these two types of processes feed back on one another, but it's hard to study because ecological processes happen locally and on short timescales while evolution often occurs across landscapes and over long periods of time.

A working group led by SFI Omidyar Fellow Andy Rominger meets November 27-30 to explore ways to tackle this problem. They're testing a unified approach that combines principles from statistical physics with data from modern ecosystems that have evolved, geographically isolated, in a specific chronology.

Much of our understanding of evolution comes from the fossil record. But regions like the Hawaiian Islands and East Africa's Great Rift Lakes — two examples of geographically isolated ecosystems that evolved in chronological succession — provide a living window into evolution. "You can almost treat them like a fossil record," says Rominger.

In Hawaii's case, as the Pacific Plate glided over volcanic hotspots 65 million years ago, the Hawaiian Islands began to form, one after the next, every million years or so. In that same sequence, they began to support life.

"These types of ecosystems are some of the best opportunities to merge the ecological with the evolutionary," says Rominger. They could also help us understand how ecosystems move into and then back out of steady states of equilibrium. Steady states occur when rates of input and output — for instance, energy requirements and production or immigration and extinction — balance each other out. "There are ways to guess about past ecosystems and populations of extinct species, but there's no real way to validate. Using systems along chronosequences is one way we can kind of get at that."

As human activity rapidly pushes ecosystems into non-steady states today, we're seeing non-stationary dynamics that we don't understand, says Rominger. "The ultimate goal of this work is to understand non-stationarity from its biological causes and relate that to the kind of impacts humans have on evolutionary potential."

Working group illustrates the seldom-seen side of contagion

When strangers become infected with a complex bacteria, they can no longer experience the world in isolation. Such is the predicament of the characters in *Noli Timere*, a forthcoming graphic novel based on recent scientific insights into the human microbiome and beneficial epidemics.

The developing graphic novel will show what happens when a contagion confers an unexpected benefit on its host. Rather than harming the infected, the epidemic facilitates their interconnection with fellow human beings.

According to Steve Green, the novel's illustrator: "The infection ultimately gives our main characters a newfound appreciation of the rampant transfer of microbial genes flowing between themselves and everything in their surrounding environment: people, pets, plants, and even inanimate objects in the urban environment. Even though the characters have never met, they understand each other deeply, as they have experienced life as each other; they begin to operate as a single organism."

Green is working with microbiome researcher and SFI External Professor Jessica Green (University of Oregon), storyteller Anita Doron, and the SFI postdoctoral fellows to create the graphic novel. Through *Noli Timere*, which is Latin for "do not be afraid," the collaborators hope to infect readers with a deeper understanding of how real-world epidemics can confer benefits.

Even language could be seen as a beneficial epidemic based on the way it spreads. "In the fictional story, sharing memories and 'the hive mind' as a function of an infection may seem weird and undesirable to us, but was language any different?" asks SFI Omidyar Fellow Vanessa Ferdinand.

Omidyar Fellow Chris Kempes sees the novel as an opportunity to communicate the postdocs' recent research. "Last year we produced a paper that addressed the idea of spreading beneficial elements in systems ranging from bacterial evolution to new concepts in a society," he explains. "*Noli Timere* is an opportunity for us to convey this seldom-seen side of contagion through top-notch storytelling and graphic art."

In May, the *Noli Timere* coauthors met in Santa Fe to outline the scientific and philosophical aspects of the developing novel. During the three-day SFI working group, they decided to structure the novel as co-evolving portions of the fictional narrative, interspersed with non-fiction scientific essays.

Noli Timere is still under development, and publication details will be announced in a future issue of *Parallax*.

A character from Noli Timere *(Illustration: Steve Green)*

Two SFI Complexity Explorer courses made Class Central's list of the "Top 50 MOOCs of All Time." "Fractals and Scaling," taught by **David Feldman** (College of the Atlantic) and "Introduction to Complexity," taught by SFI Science Board member **Melanie Mitchell**, were selected from ~6,000 Massive Open Online Courses (MOOCs), based on reviews by Class Central users.

SFI External Professor **Simon DeDeo's** essay, "Origin Gaps and the Eternal Sunshine of the Second Order Pendulum," was a finalist in an annual contest run by the Foundational Questions Institute (FQXi). In the essay, DeDeo argues "there are true gaps between life and non-life, mind and mindlessness, and even between functional societies and groups of Hobbesian individuals… [that] emerge from the mathematics of self-reference."

An SFI-initiated research paper is among the top 10% of most-cited articles in the journal *PLOS ONE*. "A quantitative theory of solid tumor growth, metabolic rate and vascularization" was published in 2011 and co-authored by SFI External Professor **Van Savage** (UCLA), Distinguished Professor and Past President **Geoffrey West**, and former SFI REU **Alex Herman** (University of California San Fransisco School of Medicine). It has 50 citations according to Google Scholar.

The National Science Foundation (NSF) has funded an SFI proposal for a research coordination network titled "Exploration of Life's Origins," to be led by SFI Omidyar Fellow **Chris Kempes** and SFI President **David Krakauer.** The ongoing SFI research effort will be part of the NSF's new push to support sustained integration across multiple scientific fields in order to address important problems.

New Studios deliver ACtioN-able insights

Companies are no strangers to complexity. As they interface with complex economies and human social groups, they routinely encounter emergence, feedback loops, and other complex systems behaviors. The trick is for staff to spot and manage such phenomena, encouraging the beneficial behaviors and curtailing the detrimental ones.

To that end, SFI's Applied Complexity Network (ACtioN) is offering a new program for its members. The Studio is a multi-day intensive workshop wherein a group of a firm's decision-makers convene at SFI and meet with SFI scientists to work through aspects of complexity theory that apply to their organization's specific challenges.

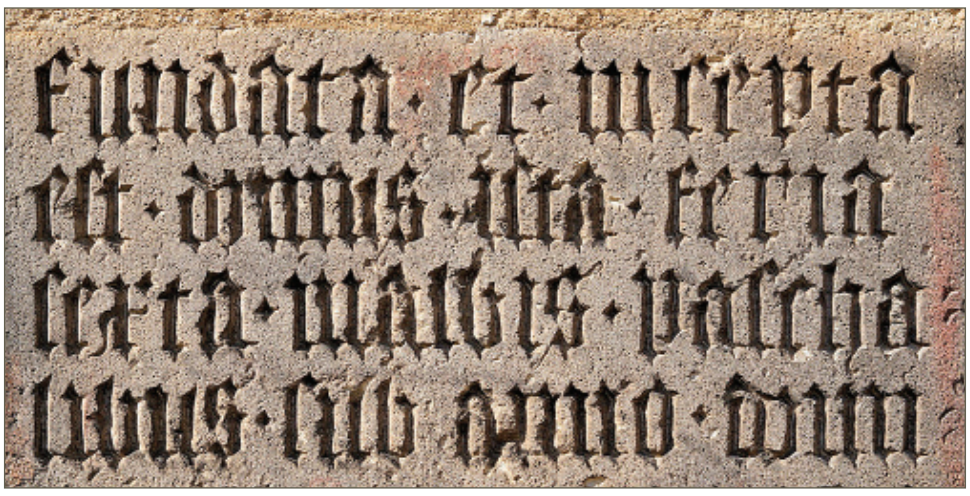
"It's a great way to see how theories developed at SFI are applied to concrete problems," says Will Tracy, SFI's VP for Strategic Partnerships who runs ACtioN and the Studio program. When an organization expresses interest in holding a Studio, Tracy works with them to establish which aspects of complexity science apply to their problem domain and match the best researchers to their Studio.

Most days start with two SFI scholars explaining principles and factors related to the day's theme. SFI Distinguished Professor and Past President Geoffrey West, for example, has used insights on biological scaling to talk about expected lifespans of companies vis-a-vis organizational bureaucracy; Mirta Galesic, SFI's Cowan Chair in Human Social Dynamics, discussed research findings about group decision-making and implications for structuring such processes; and External Professor Brian Arthur has shown how the elements of true technological innovation can foster radical breakthroughs.

After each day's initial executive education session, the Studio participants discuss how the theories they learned apply to their organization's challenges. Later in the day, they re-convene with the SFI faculty to discuss these applications, and refine their approaches.

Tracy ran three of these Studios in as many months this summer. "Everyone we worked with so far has asked about doing more within a week of the first one."

To learn more about SFI's Applied Complexity Network, email ACtioN@santafe.edu.



Let us compute: The law

Legal systems generate staggering amounts of text, from judge's decisions to court orders to lengthy wordings of regulations, rules, and laws. And text is data. From one point of view, these data encode the structure and evolution of our attempts to govern. From another, they represent a rich dataset waiting to be excavated by the tools of big data.

Merge those perspectives, and you find a burgeoning research field in the computational study of law. For years, SFI External Professor Daniel Rockmore (Dartmouth College), a computer scientist, has been engaged in interdisciplinary collaborations that apply the tools of computer science and network analysis to legal documents. (In a recent work, the researchers used evolutionary biology models to analyze how constitutions change over time.)

Many of those collaborations have involved Michael Livermore (University of Virginia School of Law), much of whose research focuses on using computational tools to better understand the law. Together, and with others, they've applied techniques from a range of disciplines including network analysis, computational text analysis, and natural language processing to conduct an empirical study of the law. They've produced, for example, an online search engine that can both identify legal documents and make recommendations to a user of other useful documents.

Now, they're bringing together leading researchers in the field for a working group at SFI, to be held December 11-14. It's the first meeting in a new research theme at the institute, The Feldstein Program on Law, History, and Regulation.

"Our goal is to set the stage and coalesce the work that's been done in the computational study of law," Livermore says. The lineup includes an international mix of leading economics, political scientists, legal scholars, and computer scientists.

Livermore hopes the working group will inspire new computational tools that can produce more sophisticated ways of understanding legal systems. These tools would be useful for any system; they also might be used to study relationships between legal systems or track how legal ideas spread over time. "Anywhere the law matters, which is everywhere, the work is applicable," he says.

SFI welcomes new External Faculty

AMY BOGAARD

Professor of Neolithic and Bronze Age Archaeology (University of Oxford)

Amy Bogaard works at the intersection of archaeology and archaeobotany to explore early farming practices and land use in Europe and western Asia. Collaborating with plant ecologists, isotope geochemists, agronomists, and economists, she aims to understand how those practices have evolved into present-day traditional farming.

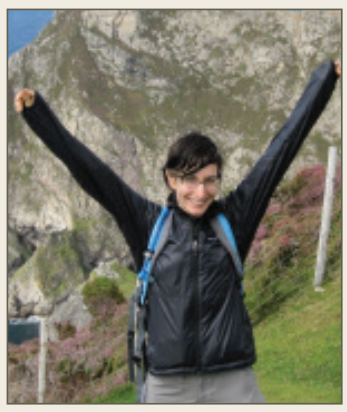
Bogaard is currently leading the European Research Council's Agricultural Origins of Urban Civilization (AGRICURB) project, which aims to refine and integrate new methods of reconstructing past crop growing conditions to evaluate the nature and social significance of farming practices in Europe and Western Asia. Her other current projects range from excavations in Knossos, Crete; studying economic integration and cultural survival in Neolithic Turkey; and developing new approaches to palaeodietary and agricultural reconstruction.

Earlier this year, Bogaard co-taught a graduate/post-graduate short course at Oxford, "Inequality: Archaeological and Economic Perspectives" with SFI Professor Sam Bowles. The course attracted wide interest in the School of Archaeology and enhanced the profile of multidisciplinary approaches to social inequality at Oxford.

Bogaard earned her Ph.D. at the University of Sheffield and received the Shanghai Archaeology Forum Research Award for her AGRICURB and paleodietary projects.

ELIZABETH BRUCH

Associate Professor in Sociology and Complex Systems (University of Michigan)



Elizabeth Bruch has explored a broad array of population phenomena where the actions of individuals, families, couples and neighborhoods are dynamically interdependent. Her early work blended statistical and agent-based methods to examine the relationship between individuals' decisions about where to live and patterns of residential segregation.

Bruch is currently developing "cognitively plausible" statistical models that aim to represent individuals' underlying decision processes using new data sources like mobile devices and the Internet along with existing choice models. She uses "big data" as behavioral data to observe how people explore their environment, engage in novel or habitual behaviors, interact with others, and learn from past experiences.

Working with a treasure trove of data on how millions of individuals search for and pursue mates, Bruch is uncovering new methods and theoretical frameworks for understanding the link between human behavior and social dynamics. Her latest project looks at mate preferences and marriage market dynamics in the world of online dating.

Bruch earned her Ph.D. from the University of California Los Angeles, and was a Robert Wood Johnson Health Policy Scholar. Her article on racial tolerance and race-ethnic segregation, Neighborhood Choice and Neighborhood Change, won the Gould Prize, and the James S. Coleman and Robert Park Best Article awards from the American Sociological Association.

BARBARA GROSZ

Higgins Professor of Natural Sciences (Harvard University)

Barbara Grosz develops computational theories and methods that enable computer agents to work effectively with people over the long term in uncertain, dynamic environments. Her current research explores ways collaborative multi-agent systems and collaborative human-computer interaction design can improve the systems patients and physicians use for health care planning, coordination, and communication. She also investigates uses of models of collaboration for science and math education.

Grosz's contributions to Artificial Intelligence include pioneering research in dialogue processing and multi-agent systems collaboration and their application to human-computer interaction. A member of the National Academy of Engineering and the American Philosophical Society and fellow of several scientific societies, she received the 2009 ACM/AAAI Allen Newell Award, the 2015 IJCAI Award for Research Excellence, and the 2017 Association for Computational Linguistics Lifetime Achievement Award. Known for her role in the establishment and leadership of multidisciplinary institutions, she is widely respected for her many contributions to the advancement of women in science.

Grosz received her undergraduate degree from Cornell and Ph.D. in Computer Science from the University of California Berkeley. A member of the SRI International AI Center before joining the Harvard faculty, she has also taught at the University of Pennsylvania, Stanford University, and Hebrew University.

SRIVIDYA IYER-BISWAS

Assistant Professor of Physics and Astronomy (Purdue University)

Using rapid, iterative feedback between theory and experiments, Srividya Iyer-Biswas works to discover the basic physical laws that govern the probabilistic behavior of single cells, and that transcend details of specific biological systems. Her research uses a top-down physics approach rather than more traditional approaches that focus on the cartography of genetic networks and on molecular details.

Iyer-Biswas and her team have reported predicative scaling laws governing the stochastic growth and division of cells, and have developed a theory that reveals the emergence of

> MORE ON PAGE 5

a scalable, cellular unit of time. Her current work involves extending these results to thermodynamics of organismal computation, time-dependent phenomena involving cellular decision-making, and laws that dictate complex biological and social phenomena.

Iyer-Biswas began her career as a theoretical physicist, then transitioned to experimental biophysics as a post-doc at Princeton University and the University of Chicago. Through her interdisciplinary work — combining theory and application, and spanning physics and biology — her goal is to ultimately advance the fundamental physics of living systems. Iyer-Biswas was named a 2017 Scialog Fellow for Molecules Come to Life.

ANDREW LO

Charles E. and Susan T. Harris Professor, Sloan School of Management; Director, Laboratory for Financial Engineering (Massachusetts Institute of Technology)

Andrew W. Lo draws on finance, economics, evolutionary biology and ecology, cognitive neuroscience, computer science, and engineering to tackle problems related to investment strategies, investor behavior, risk management, regulatory policy, and how research ideas can be can be applied to real world situations.

Much of his research over the past two decades has been devoted to understanding the impact of human behavior on financial markets and policy, culminating in his new book, *Adaptive Markets: Financial Evolution at the Speed of Thought.*

Lo's current research expands on this work, including developing new methods for measuring and managing risks in the financial system and researching new business models and financial structures to support scalable and profitable biomedical research and drug development. He is also applying machine-learning and natural language processing to develop real-world solutions to common financial industry challenges.

Lo received his Ph.D. in economics from Harvard University, and has taught finance at the University of Pennsylvania's Wharton School. He is currently co-editor of the *Annual Review of Financial Economics* and an associate editor of the *Financial Analysts Journal, the Journal of Portfolio Management*, and the *Journal of Computational Finance*. His awards include the Alfred P. Sloan Foundation Fellowship, a Guggenheim Fellowship, and awards for teaching excellence from both Wharton and MIT.

SONJA PROHASKA

Professor and Group Leader, Computational EvoDevo (University of Leipzig)

Sonja Prohaska studies gene regulation, from the theoretical consideration of the gene concept to the evolutionary history of special genetic regulatory mechanisms.

Drawing from both her computer science and genetics background, she seeks to investigate whether epigenetic regulation — sitting "on top of" the DNA — can be understood as a computation device. And using modeling and computer simulation, she is working to uncover the causes of cell differentiation.

Working across multiple disciplines at SFI, Prohaska will explore evolution – a central theme of her research - as it relates to technology, culture and language. She hopes to introduce more theory to the life sciences and to go beyond individual models toward universal theories.

On a recent visit to SFI for back-to-back workshops on the thermodynamics of computation in chemical and biological systems, Prohaska was part of a team working to collect and review ideas on what it is that biological systems compute.

Prohaska is a professor and project leader for Evolution and Development at Leipzig University's Interdisciplinary Center for Bioinformatics and leads Computational EvoDevo at the University's Institute of Computer Science, where she earned her Ph.D. in Bioinformatics.

GEORGE STAROSTIN

Linguistics Researcher (Russian State University of the Humanities)

George Starostin has spent over a decade at the Center of Comparative Studies and the Department of Far Eastern Philology of the Russian State University for the Humanities, where he advances the work of his late father, Sergei Starostin, formerly Russia's leading specialist in comparative linguistics.

As co-director of the SFI-coordinated international *Evolution of Human Languages* project, initiated by Dr. Murray Gell-Mann, Starostin has made important contributions to the study of the linguistic prehistory of humanity, working toward a global phylogenetic classification of the approximately 6000 languages spoken today, similar to the classification of biological species. He has also been instrumental in the development of *The Tower of Babel*, an online system of etymological databases for the world's languages started by his father.

Starostin is currently focused on the languages of Africa, including hypothetical language families such as Nilo-Saharan and Khoisan (formerly known as Bushman-Hottentot) of South Africa. This field remains particularly challenging due to the extreme complexity and unique features of these languages, including the Khoisan "click" phonemes, which do not occur in any other language family.

Starostin received his Specialist degree in theoretical and applied linguistics and defended his Candidate thesis in comparative Dravidian linguistics at the Russian State University of the Humanities in Moscow.

Real-world problem solving comes to online complexity learning

Participants in SFI's online education platform, Complexity Explorer, now will be able to test their new knowledge on a tangible, real-world problem.

"At the end of the day, it doesn't matter how much book learning you have or how many problem sets you solve," says SFI External Professor John Miller. "Creative, interdisciplinary complex systems thinking is best tested when applied to the real world."

In August, Miller and SFI's Education team introduced the Complexity Challenges, exercises meant to engage Complexity Explorer participants in open-ended, real-world problem-solving.

Here's how a Challenge works: SFI teams up with a partner institution (often a member of the Applied Complexity Network) to identify a problem or business obstacle. Miller abstracts that problem into an open-ended puzzle for participants to solve any way they want.

Participants have one month to generate their solutions and to deliver short written theses and three-minute video presentations. They then review each others' submissions. Mentors and partner-institution reps rank the top-scoring submissions.

"We don't have some 'right answer' in mind," Miller says. "What we care about is good solid scientific thinking that uses the various tools and ideas from complex systems science to derive novel solutions."

For the inaugural challenge, which began August 16 and ends September 30, SFI teamed up with the MITRE Corporation and its longtime SFI ACtioN representative Matt Koehler. Fifty participants from SFI's alumni and Complexity Explorer communities have signed up to participate.

The problem has to do with decentralized delivery – think warehouse organization, package delivery, airline routing, or self-driving ride services. In this case, the problem is abstracted as a giant checkerboard, with the challenge of getting checkers from varying starting and ending points using only simple rules and local information. The best two solutions will win a cash award.

"Because participants don't know about the original concept behind the abstracted question, the solutions they come up with will potentially be really diverse," says Gabby Beans, SFI's Program Manager of Online Education.

Complexity Challenges bring benefits to all involved, she adds. "For the ACtioN members, we're hoping they get some creative solutions," she says. "For the students, along with the unique learning opportunity, we're also hoping to showcase their talents to potential employers."

In the future, if successful, Complexity Challenges may form the basis of capstone projects for online certificate or degree programs offered by SFI, she says.

More at https://www.complexityexplorer.org/challenges.

SFI Press *(cont. from page 1)*

chapters by archaeological colleagues engaged in uncovering universal patterns in the emergence of complex societies like the Maya.

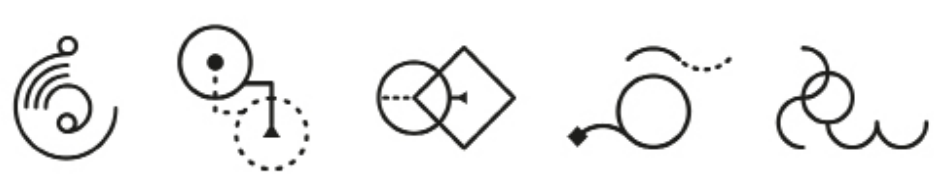
Work is revving up on the five titles already in the SFI Press publication pipeline, says Laura Egley Taylor, Miller Omega Design Coordinator at SFI. Taylor and Editorial Assistant Lucy Fleming handle all of the copyediting and design for the press, and work with Amazon to complete the publication process.

Distinguishing SFI Press's competitive edge is nimbleness coupled with economy: moving quickly to literally imprint new thought incarnating at SFI — and making the price right for fellow scientists and the public.

The SFI Press is made possible through the generous support of the Feldstein Program on History, Regulation, & Law, and the Miller Omega Program.

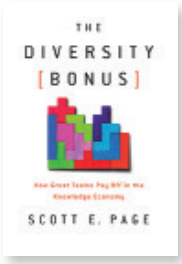
List of attendees
(cont. from Beyond Borders, page 2)

John Beggs, (Indiana University); ASU-SFI Center Postdoctoral Fellow **Bryan Daniels**, SFI External Professor **Simon DeDeo**, (Carnegie Mellon); SFI External Professor **Doug Erwin**; (Smithsonian Institution); SFI Professor **Jessica Flack**, SFI President **David Krakauer**; SFI External Professor **Manfred Laubichler** (Arizona State University); **Doug Moore** (Arizona State University); **Ariana Strandburg-Peshkin** (Max Planck Institute for Ornithology in Konstanz, Germany); SFI External Professor **Olé Peters** (London Mathematical Laboratory); **Pawel Romanczuk** (Humboldt University of Berlin); **Colin Twomey** (Princeton University); and SFI Professor and Past President **Geoffrey West** attended the Future of Computational Social Science working group, held August 8-9 at SFI.



Above: Establishing the SFI Press's typographical identity has entailed commissioning a "complexity alphabet" of 26 typographical symbols. The glyphs appear in a table the back of every book. The complexity alphabet was designed by Brian Williams of Karmarama in London

New books by SFI authors



The Diversity Bonus: How Great Teams Pay Off (Princeton University Press, 2017) by SFI External Professor Scott Page (University of Michigan) investigates how businesses and other organizations can improve their performance by tapping a variety of cognitive repertoires. Page traces a causative path to the benefits that arise when teams composed of different kinds of thinkers come together to think, solve, and create. These "diversity bonuses" include improved problem solving, increased innovation, and more accurate predictions — all of which lead to better performance and results.

The Economy (Oxford University Press, 2017) is a textbook designed for a first course in economics. Available in paperback format and as a free, online interactive text, the book aims to address the gap between complex, real-world economic problems and the topics traditionally taught in first-year courses. Several SFI co-authors contributed to its content as part of the Curriculum Open-access Resources for Economics (CORE) project — an international collaboration of economists, teachers, and students led by Wendy Carlin (University College London) and SFI Professor Sam Bowles.

Maya E Groups (University Press of Florida, 2017) is an anthology edited by David Freidel (Washington University), Arlen Chase (University of Nevada), Anne Dowd (ArchaeoLOGIC USA, LLC), and SFI Trustee Jerry Murdock. The book results from an ongoing series of SFI meetings exploring ancient Maya culture. E Groups, named after "Group E" at an archaeological site in Uaxactun, are some of the earliest permanent public structures that were ritual centers and astronomical observatories.

History, Big History, & Metahistory (SFI Press, 2017) compiles a classic series of SFI writings that lay groundwork for a macroscopic understanding of written history. Edited by SFI President David Krakauer, John Gaddis (Yale), and Kenneth Pomeranz (University of California Irvine), the collection brings together insights from distinct fields because, according to the editors, "it seems likely that the disciplines themselves develop less than optimally when they lack ready access to each other's insights and methods."

SFI welcomes new Postdoctoral Fellow

Deepak Bhat seeks to understand systems in nature that have remained unsolved by classical statistical approaches. Such systems — biomolecules such as motor proteins, bacteria exhibiting chemotaxis, and fluctuations in stock markets, to name a few — are often characterized by a noisy environment, and are out of equilibrium.

To better understand the macroscopic properties of these systems, Bhat uses tools from the nascent field of non-equilibrium statistical mechanics. In recent years he has studied the statistics of a molecular motor transport process that organizes structures inside a cell. He has also been exploring the connection between information theory and thermodynamics through a hypothetical, thermodynamic engine. His other research interests include stochastic thermodynamics of small systems, problems based on random walk models, first passage time problems, bacterial chemotaxis, active matter systems, and cytoskeletal filament dynamics.

Bhat joins SFI as a Program Postdoctoral Fellow, under the mentorship of SFI Professor Sidney Redner. He received his Ph.D. from Indian Institute of Technology Madras, Chennai and Master of Science from Indian Institute of Technology Guwahati. He comes to SFI following a postdoctoral fellowship at the International Centre for Theoretical Sciences, Bangalore.

Limits *(cont. from page 1)*

in light of the methods that scientists currently use. In Grochow's words, "We will ask about the real foundations of the kinds of tools that we are using, and we will try to place these on firmer ground."

Proposed participants include philosophers, journalists, novelists, and scientific researchers, but the majority of invitees are practicing scientists who regularly confront the workshop's questions in their research. The workshop will take place at SFI from Nov. 29-Dec. 1.

Ultimately, the organizers hope that the workshop will clarify not only where the limits to scientific understanding lie, but also how science can surpass them.

When species compete, it's a colossal game of rock-paper-scissors

Organisms competing for contested resources like nutrients, light, and space play an important role in biodiversity. A recent paper co-authored by incoming SFI Omidyar Fellow Jacopo Grilli finds that the number of competitors may matter.

"The authors' model potentially offers a better understanding than that provided by previous models of how diverse communities are maintained in nature, where it has often been hard to explain the high levels of biodiversity observed," writes former SFI Omidyar Fellow James O'Dwyer (University of Illinois), in a review of the paper.

Think of two saplings seeking to exploit the advantages of light streaming through a new opening in the forest canopy. One will emerge the winner in this simple pairwise contest.

But add a third sapling and predicting a winner is far less straightforward, like predicting who will win in a three-person game of rock-scissors-paper. Rock smashes scissors, but while paper covers rock, it also answers to scissors.

Now imagine the game with hundreds or thousands of different competitive moves. In their model, Grilli and co-authors did just that. They also made their competition a bit "noisy" by allowing non-standard outcomes every so often (this time, scissors cuts rock) — much like in nature, where many factors, from soil chemistry to hungry insects, can make outcomes less predictable.

As they tweaked the model's parameters — by allowing new species to enter the system, for example — they were able to probe the dynamics of competition and diversity in new ways.

Their analysis proffers, among other insights, that higher-order interactions — those involving multiple competitors — may play a significant role in stabilizing an ecological system.

"The jury is still out on whether this is the right way to describe ecological competition," says O'Dwyer, "but these results suggest these higher-order interactions are something to look for in real systems, and the model at least makes it more tractable to study these effects."

The intersection of Grilli and O'Dwyer's work — and their common SFI pedigree — is no coincidence. Both are ecologists with backgrounds in physics. About five years ago, Grilli read one of O'Dwyer's papers and was drawn in by its physics-inspired approach — one Grilli had already been thinking about. Grilli had not heard of SFI, but his interest in O'Dwyer's paper eventually led to his application for the Fellowship.

"It's nice to see two generations of Omidyar Fellows constructively building on and challenging each other's work, and, in doing so, pushing complexity science in ecology forward," says SFI Professor Jessica Flack. "It speaks to the strength of this unique postdoctoral fellowship."

Grilli's paper and O'Dwyer's review were published Aug. 10 in *Nature*.

Social reactors, past and present

What do you lose by moving to the suburbs?

A lot, according to an SFI working group examining human settlements over thousands of years. Cities are "social reactors" — accelerators of human interactions and their outcomes. And these outcomes can include everything from marketplaces and sewage systems to moral philosophy and cell phones.

For thousands of years, humans were mobile hunter-gatherers. When we started staying in the same place for longer periods, things began to change — and fast. "It appears that everything since then is just the playing out of a series of relationships that emerged when people started settling down," according to the working group's organizer, SFI External Professor Scott Ortman (University of Colorado).

By quantitatively analyzing human settlements from ancient times to the present, Ortman's group has found that the more things change, the more they stay the same. In fact, says Ortman, "in our framework, there's not much difference between a Neolithic farming village and a modern city."

The researchers work with a variety of archaeological measurements such as the density of potsherds or size of monuments, as well as historical records and ethnographic studies of contemporary hunter-gatherer societies.

Still, the archaeological record presents thousands of "long-term experiments" in which human groups have tried to harness these social networking processes — and they do so in ways that differ from our typical experience.

Our concept of commuting, for example, assumes that cities have one "downtown." But the Pueblo peoples' traditional social and economic system involves events in different villages on different days — essentially creating many city centers. This "polycentric commuter flow" allows them to gain the benefits of larger scale despite the smaller size of individual communities.

So, is your commute worth it? In exchange for your big backyard, you'll spend part of the day traveling. It's hardly nomadic — but sacrificing that space for more time bartering, arguing or innovating with other humans has, arguably, fueled the modern world, the researchers say.

More at http://www.colorado.edu/socialreactors/project-news

Portion of mural by Diego Rivera showing the Aztec city of Tenochtitlan. (Photo: Wolfgang Sauber)

RESEARCH NEWS BRIEFS

Pigtail macaque (Image: AJ Haverkamp)

MECHANISTIC MODEL DESCRIBES BIRD MIGRATION

A collaboration that began during the 2016 Complex Systems Summer School has resulted in a new paper, published in August in *Nature Scientific Reports*. CSSS alums Christopher Revell (University of Cambridge) and Marius Somveille (University of Oxford) borrowed ideas from physics to develop a mechanistic model of bird migration. Most animal migration studies rely on statistical analysis of tracking data and don't provide understanding of the underlying forces driving migration. To better elucidate these forces, the researchers combined datasets of wind velocity and food density to produce an environmental potential landscape that accurately predicts migratory patterns for several albatross populations, allowing better predictions for how migration patterns might respond to environmental change.

WHEN WINNING WARS WAS A MATTER OF MARRYING WELL

For rulers in pre-modern states, marrying the right wife was often a path to military victory. In a paper published in the Journal of Archaeological Method and Theory, SFI External Professor Paula Sabloff looked at several pre-modern states to uncover the strategies their rulers used to win wars — or at least, reduce the risk of losing them. Sabloff found that, with remarkable consistency, marriage alliances helped pre-modern rulers form networks of military support. By giving and receiving royal wives, rulers sustained patron-client relations — contracts of obligation between unequal parties that lasted the life of the marriage, and often beyond — that might have been established through conquest or other means.

> MORE NEWS BRIEFS ON PAGE 6