Fall 2019

Parallax

THE NEWSLETTER OF THE SANTA FE INSTITUTE

New fellowship bridges theory, application

Since its inception, the Santa Fe Institute has operated well beyond the confines of traditional boundaries. SFI's meetings, educational programs, and long-term projects eschew the typical disciplinary silos prevalent at many universities and research centers. Now, through the new Applied Complexity Postdoctoral Fellowship, which launched September 1, SFI is bridging another divide — the gap between academia and industry.

This fellowship offers early career researchers the opportunity to work closely with SFI faculty and with decision-makers in industry and government, and to use insights from complexity science to address specific challenges and questions raised by industry sponsors.

"This fellowship is a first-of-its-kind at a theoretical research institution," says Will Tracy, SFI's Vice President for Applied Complexity. "We had more than 100 applicants, which illustrates the staggering drawing power of the Institute, but also the interest in the under-explored interstitial space between theory and application."

While the program helps industry apply SFI science, it is also designed to further the science itself. "We've found existing research with strong faculty support which we believe will be enhanced by these collaborations," says Tracy. "It's a two-way street, and the fellows are a conduit between the research at SFI and industry partners."

Joshua Garland and Michael Price , the inaugural Applied Complexity Fellows, are familiar faces at SFI; they join the new fellowship from their positions as Omidyar and ASU-SFI postdoctoral fellows, respectively. Over the next two years, they will be helping to hone and design the future of the program while working on two specific projects.

Garland, who holds degrees in mathematics and computer science, will work closely with SFI Professor Mirta Galesic on a project aimed at tackling online hate by researching counterspeech. Garland anticipates that by partnering with social media companies and gaining deeper insight into the algorithms behind the platforms, he will be able to apply the latest advancements in social science, machine learning, and natural language

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Lions sleeping in a tree (Image: R. Rees)

Biological and physical time meet in sleep

Sleep is a confounding phenomenon: Everybody does it, but no one has a precise understanding of why we sleep or what sleep does to our brains. And to researchers in a broad variety of fields, from biologists who study sleeping flies to clinicians treating sleep disorders, the pull of sleep is irresistible.

"It's obviously essential to life, it's persisted across millions of years of evolution, and it's altered in a large range of brain disorders," says cognitive neuroscientist and psychiatrist Alex Herman at the University of Minnesota, "but we know so little about it."

Sleep is deeply tied to learning, bodily health, brain development, and aging, but its function in the processes largely remains a mystery. It's also inextricably tied to time, says SFI External Professor Van Savage, a mathematical biologist at UCLA. For example: "How long do you sleep? How long is REM [rapid-eye movement] sleep?" he asks.

Sleep patterns change from birth to adulthood, and, in general, people sleep less as they get older. Researchers have also observed patterns associated with organism size: Mice sleep for 16 hours per day, while blue whales, the largest animals on the planet, sleep for only 1.5.

Savage and Herman have organized a working group with invitees from a wide range of fields, all united by their interest in sleep. The working group, to be held at SFI over three days in November, will begin to unpack the causes, timescales, and consequences of sleep. In particular, participants will focus on how sleep time changes across species, and how it changes with age and during adulthood.

The working group is part of SFI's Complex Time: Adaptation, Aging, and the Arrow of Time research theme, which looks at how adaptation and entropy play out in complex systems. The study of sleep suggests new ways to think about how biological time, represented by aging or changing sleep patterns, for example, are entangled with physical time, determined by the regular movement of Earth around the sun.

"Understanding how these multiple clocks are coupled together is very much what we mean when we talk about complex time," says Amy P. Chen, who manages the program at SFI. But understanding those connections requires a multidisciplinary effort, she says. "We want to get the people who don't usually talk to each other in the same room."

The researchers' goals for the working group include novel collaborations and, ultimately, a book in the SFI Press to collect new insights in the field. The Complex Time research theme is funded by a grant from the James S. McDonnell Foundation.

Can evolution reveal how life emerged from chemistry?

All life that we see on Earth originated from a population of organisms that biologists call the Last Universal Common Ancestor — a single-celled life form that likely lived off the energy in deep-sea hydrothermal vents. Though all organisms carry traces of this billions-year old ancestor in our DNA, we know very little about how life's progenitor emerged in the first place. How did the originator . . . originate?

A group of biologists think that a new synthesis in evolutionary theory might help answer this question. The working group, to be held November 13-15, is part of SFI's ongoing Research Coordination Network for Exploration of Life's Origins, sponsored by NASA and the National Science Foundation. In the spirit of the larger research program, the November meeting will bring together evolutionary theorists and experimentalists to explore which evolutionary models might best explain how chemical systems become biological systems.

The group will ask not only about the import of existing models; it will also ask what is missing from current theories that could account for selection-like processes in prebiotic systems that are the precursors to adaptive evolution.

Generating a theory that bridges chemistry and biology entails "thinking about chemical evolution in a new way," says SFI Professor Chris Kempes, who is co-organizing the group with geneticist David Baum of the University of Madison and computational biologist Oana Carja of Carnegie Mellon University. Since Kempes is a theoretical physical biologist who often works on astrobiology, he's ultimately interested in arriving at "general principles for life anywhere in the Universe."

For Carja, the workshop will be a forum to explore whether, and how far, her research on the spatial and temporal constraints on evolution can apply in a prebiotic context. "Can we use existing evolutionary theory to understand the precursors to life?" Carja asks, "Or are conditions so different that we need entirely new frameworks?"

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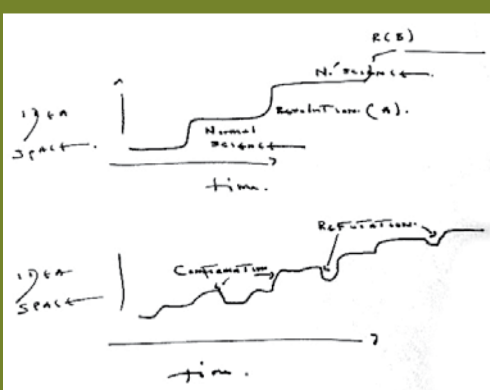
Thermophilic bacteria lend color to Yellowstone's Grand Prismatic hot springs. (Photo: Mitchell Rouse / iStock)

BEYOND BORDERS

NEW COMPLEXITY ECONOMICS

There are broadly speaking two schools of thought examining the progress of science, one evolutionary and one revolutionary. The evolutionary schools are exemplified by the philosophers of science, Karl Popper and Imre Lakatos. Popper argued that science proceeds through a combination of bold conjecture and ruthless empirical refutation. Lakatos extended Popper's framework adding that ideas can also receive empirical confirmation. The culture of science thereby maintains an informal score card registering wins and losses with dominant ideas receiving the highest aggregate score. This sum is the definition of objectivity.

Thomas Kuhn was the most vocal champion of the revolutionary school arguing that most science is normal or incremental (as per Popper and Lakatos) but that occasionally "paradigm" shifting ideas overturn prior beliefs, replacing them with radically new models, often achieved through an equally radical simplification in theory.



Revolutionary (top figure) and evolutionary (bottom figure) views of scientific change. In some suitable space of ideas Kuhn describes discontinuous, revolutionary transitions between epochs of approximate stasis — normal science. Popper and Lakatos describe science as a continuous process of idea generation, refutation, and confirmation. All three agree that the average trend has a positive slope. (Image: David Krakauer)

The natural sciences have provided most of the intellectual natural history upon which Popper, Lakatos, and Kuhn base their ideas. The Copernican Revolution, quantum mechanics, special and general relativity, Mendelian genetics, Darwinian natural selection, plate tectonics. In all of these cases it is rather easy to demonstrate that previous ideas were either refuted or deprecated in favor of new ideas that could account for a broader range and higher resolution of empirical observation.

What of the social sciences? I have wondered what might count as an unassailable refutation or a revolutionary idea in the social sciences. In particular in the field of economics. I have posed this question to two Nobel-winning economists who chose to abstain from answering. My friend, Sir Partha Dasgupta, the Frank Ramsey Professor Emeritus of Economics at the University of Cambridge, answered without hesitation: game theory. Partha argued that the mathematical formalization of strategic interactions under uncertainty changed the way that economists conceptualized agents, incentives, and markets. I suspect that a similar revolutionary case could be made for Adam Smith's invisible hand, the Keynesian multiplier, and Ricardian trade theory.

Complexity science aims to provide fundamentally new ways of thinking about the adaptive universe and to do so in a way that reveals common structures that exist independently of the contingencies of disciplinary histories. Thus in principle a revolutionary idea in complexity science could be as revolutionary in economics as in cell biology, neuroscience, and sociology. And this is a truly stunning thought: no longer would an idea be confined to a field but extend across specialties transforming them all. What better argument could there be for pursuing a career in complexity science?

This is of course not as odd and unprecedented a possibility as it might seem. Game theory is part of the standard tool kit of ethology, ecology and evolution, and evolutionary game theory is a standard approach in economics. Network theory is applied across technological networks, social networks, genetic regulatory networks, and ecological networks. Methods and mathematics are often domain independent. But what about going beyond methods to encompass fundamental frameworks? For

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SFI IN THE NEWS

The American Political Science Review's new 12-woman editorial board, co-led by former SFI faculty member Elizabeth Jean Wood, was featured in *Quartz* and *The Washington Post*.

The *CBC* highlighted Geoffrey West's scaling research in a feature about fractals and other recursive patterns in nature.

The *Boston Review* profiled Sam Bowles and his father, Chester Bowles, who, in 1946, wrote a pamphlet titled "Tomorrow Without Fear." The pamphlet emphasized the importance of raising wages along with productivity.

In separate articles, *Aeon* magazine featured External Professor Paula Sabloff's latest paper on how royal women exercised power; VP for Science Jennifer Dunne's description of the ecological benefits of prey-switching; and External Professor Ole Peters' "ergodicity" approach to economics, which re-conceptualizes the foundational concept of how individuals approach gambles.

Vox featured research by External Professor Jessika Trancik's lab showing that the cost of battery technology and other energy storage systems are "within striking distance" of enabling widespread adoption of renewable energy sources.

Knowable Magazine published a Q&A with Jerry Sabloff, "Archaeology of the 99%," which coincided with the publication of his perspective piece in the 2019 *Annual Review of Anthropology*.

In a podcast for *The Santa Fe New Mexican*, External Professor Rajiv Sethi explored the power and pervasiveness of stereotypes in the criminal justice system — the subject of Sethi's new book, *Shadows of Doubt*.

Hakai Magazine covered a series of papers by former SFI Complexity Postdoctoral Fellow Andrew Berdahl in the feature "Do Salmon Make Decisions as a Group?" Berdahl, now on the faculty at the University of Washington, notes that much of the research on collective behavior was undertaken at SFI.

And in *WIRED*, Science Board co-chair Melanie Mitchell wrote in an op-ed that AI language systems can pass standardized tests, but still lack the common sense of preschool-aged children.

NEW FELLOWSHIP BRIDGES THEORY, APPLICATION *(cont. from page 1)*

processing to develop tools that empower citizens to counter cyberhate and make entire networks simply less conducive to hate.

"This fellowship offers an opportunity to make an actual impact," says Garland. "Paper after paper [about radicalization and hate speech online] is coming out and landing in the arXiv. Now I'll get a chance to put this research into effect and create positive change."

Price, with a background in physics and anthropology, will work primarily with SFI Professors Geoffrey West and Chris Kempes to expand the applications of scaling theory. Originally, scaling theory revealed patterns in mammals, and more recently, has helped illustrate tradeoffs among organisms of different sizes, and to determine the ultimate limits for certain organismal types. And now, researchers are exploring how scaling theory applies to human organizations including cities, firms, and universities. Price hopes to develop a deviation index to identify when, and understand why, an organization is under- or over-performing relative to its size.

Already, research from complex systems has offered transformational insights to specific industries. Price notes that two areas of research — the thermodynamics of computation and scaling theory applied to human systems — have recently offered new insights with the potential to revolutionize existing industries or create new ones, and to make sense of human dynamics within companies. Through his Applied Complexity Fellowship, Price says, "I hope to add new and surprising ideas to these two examples."

In addition to their main projects and laying the groundwork for the future of the fellowship, Price and Garland will also be collaborating with one another. "We have a goal of spending time on the other person's project," says Price. "There's a lot of interaction in this fellowship, which gives it a lot of richness."

This won't be the first time for either Garland or Price to work on translating complex systems science for non-specialist audiences and in industry settings. Between completing his undergraduate degree and beginning his Ph.D., Price worked as a systems engineer at Raytheon Space and Airborne Systems. Garland has used his mathematics background to consult for financial firms and social media companies.

Applied Complexity Fellows Joshua Garland and Michael Price. (Photo: Katherine Mast)

"Translating science to industry is often very challenging," says Garland, noting that what a company wants may be in conflict with what his mathematical analyses suggest is possible. But good lines of communication between research and industry create the potential for powerful collaboration. "There are plenty of ideas in academia that have the potential to make a big impact in industry, and vice versa. By positioning fellows amongst the leading minds in these two groups, we will be able to leverage the fantastic ideas on both sides to derive meaningful solutions to today's most challenging problems," he says.

This fellowship also comes at an interesting time when research, particularly in certain fields, is moving out of the halls of academia and into industry. "If you want to do interesting research, especially in data science, you have to toe the line between the two," says Garland.

The products of this fellowship will also be different from other postdoctoral fellowships. In addition to papers as the tangible outcome of research, the Applied Complexity Fellows will build models, conduct analyses, and develop new vehicles to bring their science to application.

"We'll still be doing fundamental research, but, with the scaling project, a lot of the questions we're going after will be for people in academics and government," says Price. "While we understand the empirical patterns, we don't understand the mechanisms for organizational scaling the way we do in biology."

Garland, Price, and Tracy describe the new fellowship as a true win-win for both academia and industry. Sponsorship from industry partners will provide new revenue streams for the Institute, while these partnerships offer faculty and fellows new opportunities to develop solutions for big, sometimes seemingly intractable, problems.

"There is a growing belief at SFI that there is a very interesting space between pure theory and application," says Tracy. "This fellowship emerged as a way of both exploring that space and adding resources to the Institute."

In addition to sponsorship from industry leaders, the Applied Complexity Fellowship is generously supported by a gift from longtime supporter Bill Miller, SFI Life Trustee and Chairman Emeritus.

ACHIEVEMENTS

SFI External Professor **Raissa D'Souza**, an expert in network science and complex systems, has joined the journal *Physical Review Research* as Lead Editor. She also won the Network Science Society's inaugural Euler award for her influential work.

Raissa D'Souza

Former SFI Postdoc **Jeremy Van Cleve**, now an assistant professor of biology at the University of Kentucky, has received a CAREER award from the National Science Foundation. The five-year, $780,000 award will support his research into the genetic foundations of organisms' social behaviors, and will also help develop a program to teach students of all ages about the tools of data science and computational biology.

Jeremy Van Cleve

The "Majesty of Music and Math," a television production hosted by SFI Professor **Cris Moore**, won a 2019 Rocky Mountain Emmy Award in the instructional/informational category. The 58-minute feature about mathematical patterns in music and nature was produced by New Mexico PBS with the help of SFI supporter **Penelope Penland**, who also serves on the Board of the Santa Fe Symphony.

Cris Moore

SFI External Professor **Scott E. Page** received the University of Michigan's highest honor — a Distinguished University Professorship. Recipients are encouraged to "name" their positions after a mentor of their choosing; Page's new title is the "John Seely Brown Distinguished University Professor."

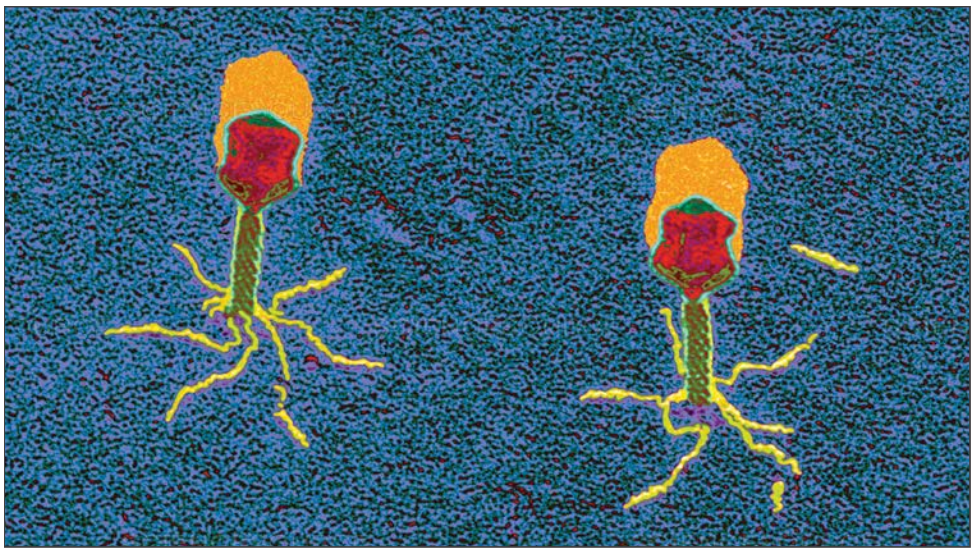
Scott Page

Complexity Postdoctoral Fellow **Stefani Crabtree** received the "Best Ignite Talk Award" at the 2019 Latin American Conference on Complex Networks, for her presentation on her ongoing research with SFI's ArchaeoEcology Project.

Stefani Crabtree

SFI External Professor **W. Brian Arthur** was named a 2019 Citation Laureate by the Web of Science group "for research revealing network effects in economic systems that produce increasing returns." The designation celebrates world-class researchers whose work is typically in the top 0.01% globally most-cited publications — demonstrating research influence comparable to Nobel Prize recipients.

Brian Arthur



T. bacteriophage viruses and E. coli. (Image: Eye of Science/ Science Source)

Working group: Exploring phase transitions in virus evolution

Last November, SFI hosted a working group for researchers from a range of disciplines — epidemiology, virology, molecular biology — who came together to compare ideas about viruses. These pathogenic parasites wreak havoc at small scales by kidnapping cellular machinery to reproduce, at slightly larger scales by infecting tissues within an organism, and at population-level scales by causing widespread disease. Yet the researchers who study these levels lack a unified theory of how these scales are all connected.

Last year's meeting launched an ongoing conversation about such a unified theory, but SFI External Professor Santiago Elena, who organized the meeting, says the exchange of ideas also exposed a slew of new challenges.

To address some of those challenges, Elena is convening a follow-up working group to be held November 4-5 at SFI. He has invited a subgroup of participants from the original, including theorists and experimental molecular virologists, to dive deeper into one of the central issues that emerged last year: phase transitions.

In physics, matter undergoes a phase transition when it changes states, as from solid to liquid, or liquid to gas. But Elena, who studies virus evolution at the Institute of Integrative Systems Biology in Valencia, Spain, says emerging evidence suggests biological systems also can undergo phase transitions. Within an infected cell, for example, individual proteins come together to suddenly form the shell, or capsid, of a new virus particle. At the population level, Elena says, the point at which an outbreak becomes an epidemic can also be seen as a phase transition.

This idea emerged at the end of last year's meeting. "There were people saying yes, saying no, and some people didn't believe at all in phase transitions," says Elena. The one thing that was clear was that they needed to keep talking about it. "There just wasn't enough discussion."

Elena suspects phase transitions may be a critical step in understanding connections between levels of virus evolution, and he hopes this year's working group can dive into questions about their role. "Can we say that phase transitions are universal for viruses at different levels?" he asks. If so, "they might help us see how one level fits on another."

New External Professors

Even before the SFI's official founding in 1984, George Cowan and collaborators envisioned an institute without departments, with renowned scholars as its faculty.

"It was all about really good people who were crossing disciplines," Cowan said.

In keeping with this vision, SFI extends and refreshes its network of researchers annually when it appoints new external faculty, affiliated with universities and institutions from around the world.

This year, we welcome 11 new researchers.

Danielle Bassett *J. Peter Skirkanich Professor of Bioengineering, University of Pennsylvania*

Wendy Carlin *Professor of Economics, Department of Economics, University College London; Research Fellow, Centre for Economic Policy Research*

Sean Carroll *Research Professor of Theoretical Physics, Caltech*

André de Roos *Professor of Theoretical Ecology, Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam*

John Krakauer *John C. Malone Professor of Neurology, Neuroscience, and Physical Medicine & Rehabilitation and Director of the Brain, Learning, Animation, & Movement Lab, Johns Hopkins University School of Medicine*

Suresh Naidu *Professor in Economics and International & Public Affairs, School of International & Public Affairs, Columbia University*

Mary O'Connor *Associate Professor, Zoology Department; Associate Director, Biodiversity Research Centre, University of British Columbia*

Orit Peleg *Assistant Professor, Computer Science Department and BioFrontiers Institute, University of Colorado, Boulder*

Marten Scheffer *Professor, Department of Environmental Sciences, Wageningen University & Research Centre*

Thalia Wheatley *Professor, Psychological & Brain Sciences; Director of the Center for Social Brain Sciences, Dartmouth College*

Karen Willcox *Professor, Aerospace Engineering and Engineering Mechanics Director, the Oden Institute of Computational Engineering and Sciences, University of Texas, Austin*

LIFE FROM CHEMISTRY *(cont. from page 1)*

Advancing a theory of life's origins could also push experimental models one step further. Experimentalists have yet to recreate chemical systems capable of adaptive evolution. With better theories, models, and simulations, however, we may be able to develop new experiments that move from generating life's building blocks, to simulating the chemical process that bring about evolving life as we know it.

BEYOND BORDERS *(cont. from page 2)*

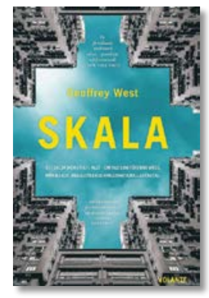
one, metabolic scaling theory has proven to be very powerful in biology and is now proving itself in social and urban contexts.

This November we are charting the evolution of complexity economics. SFI-affiliated researchers have contributed pioneering ideas and methods to the study of economic and market phenomena, including positive returns, the theory of money, agent-based models, zero-intelligence markets, maximum entropy, leverage cycles, and time series prediction. However in the last couple of decades the exponentiation of data and computer power, progress in algorithms, statistical physics, adaptive dynamics, and in neural, behavioral and cognitive science, suggests that a new complexity revolution is on the horizon. This is likely to transform all that we study at SFI, including the economy.

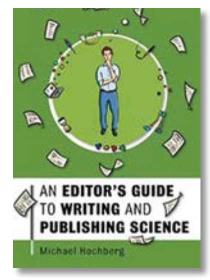
In our forthcoming November meeting, by bringing together many of our deepest thinkers on markets, trade, decision theory, behavioral economics, algorithms, and our larger community of complexity researchers, we aim to foster a Kuhnian atmosphere of paradigm-busting possibility. See you there.

— David Krakauer
President, Santa Fe Institute

New books by SFI authors

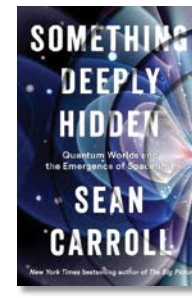


Skala (Volante, 2019) by SFI Distinguished Shannan Professor Geoffrey West is the Swedish translation of his acclaimed opus *Scale: The Universal Laws of Growth, Innovation, Sustainability, and the Pace of Life in Organisms, Cities, Economies, and Companies*. First published in British and American English in 2017, it is now available in Chinese, Dutch, Finnish, German, Italian, Portugese (pending), Swedish, and Taiwanese.



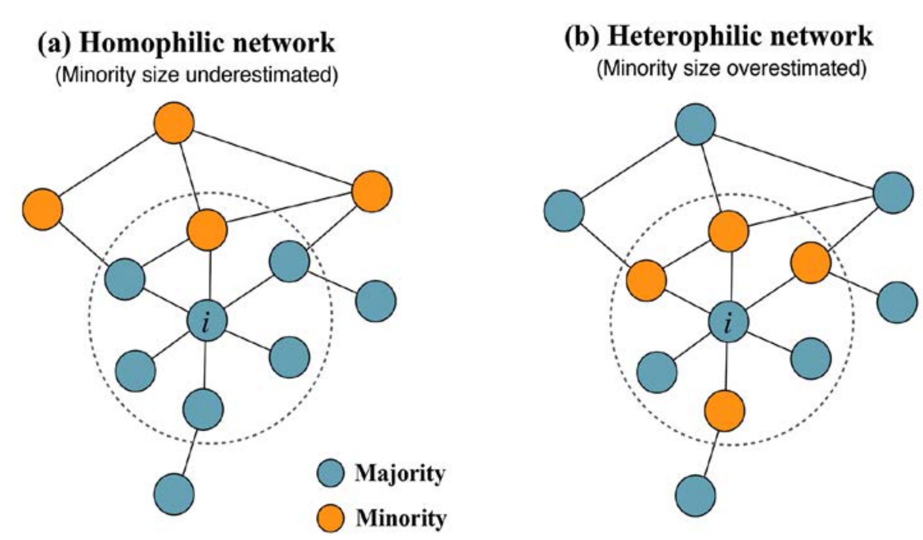
In a rapidly changing landscape for academic publishing, researchers need fresh mindsets in order to succeed. ***An Editor's Guide to Writing and Publishing Science*** (Oxford University Press, 2019) by SFI External Professor Michael Hochberg offers foundations for a new, creative approach to scientific writing. Hochberg, founder and former Chief Editor of *Ecology Letters*, has published more than 100 articles of his own and brings an insider's perspective.

Whistleblowers (Yale University Press, 2019) by SFI External Professor Allison Stanger traces episodes of whistleblowing in America and illustrates the critical, yet underappreciated, role of those who dare to call out misdeeds by those in power.



Something Deeply Hidden (Dutton Books, 2019) by SFI External Professor Sean Carroll tackles the longstanding conundrum that, although quantum mechanics underlies all of modern physics, physicists readily admit that they don't understand it. This crisis in physics can be resolved by the premise that there are multiple copies of each of us splitting off into the universe many times each second — the Many Worlds Theory of quantum behavior. Carroll makes the radical argument that spacetime and gravity naturally emerge from a deeper reality called the wave function.

RESEARCH NEWS BRIEFS



Perception bias in homophilic and heterophilic networks. (Figure: Eun Lee)

IT'S NOT YOU, IT'S THE NETWORK

Long documented in psychological literature, a panoply of social perception biases play out differently in different contexts. The 2016 U.S. presidential election was a prime example of peoples' tendency to assume that others think as we do, and to underestimate the size and influence of a minority party.

Many psychologists attribute the source of these biases to faulty cognitive processes like "wishful thinking" or "social projection," but according to a study in *Nature Human Behaviour*, co-authored by Complex Systems Summer School alum Eun Lee, SFI Professor Mirta Galesic, and their colleagues, the structure of our social networks might offer a simpler explanation. The researchers used a network model to predict that different perception biases would arise depending on two network properties: the relative sizes of the majority and minority groups, and their level of homophily (the extent to which like nodes connected to like). They then developed and administered a survey to 300 participants to test their results, confirming that perception bias could arise based solely on an individual's surroundings.

THREE CONCEPTS FROM COMPLEXITY COULD PLAY A ROLE IN SOCIAL ANIMAL RESEARCH

From bees to birds to humans, the animal kingdom is full of organisms that have evolved complex social structures to solve specific problems they encounter. Explaining why some species evolved more complex societies than others has been a fundamental challenge in the field of social animal research, and might be best approached with tools from complex systems, according to a recent paper in *Animal Behaviour.* Current and past SFI Complexity Postdoctoral Fellows Elizabeth Hobson, Vanessa Ferdinand, Artemy Kolchinsky, and Joshua Garland propose three concepts from complex systems science — scales of organization, compression, and emergence — that could be particularly useful to researchers studying complexity in animal sociality.

THE BATTERY TECHNOLOGY WE NEED TO REACH RENEWABLE ENERGY'S POTENTIAL

Whether renewable energy sources will reach their full potential will largely come down to energy storage costs, according to SFI External Professor Jessika Trancik. In a study published August 7 in the journal *Joule*, Trancik and colleagues quantify, for the first time, cost targets for storage technologies to enable solar and wind energy with storage to be cost-competitive with other on-demand energy sources such as coal, natural gas, and nuclear. They also examine what kinds of batteries and other technologies might reach these targets.

WHEN THE PATRIARCHY IS MATRILINEAL

SFI External Professor Laura Fortunato calls for clarity in a new paper published in *Philosophical Transactions of the Royal Society B*. Societies have varying systems for reckoning descent, or membership in a kinship group, and for determining other elements of social organization, including inheritance of property, succession to office, and where couples live following marriage.

"Matriliny" has become, in many cases, a shorthand for matrilineal descent, a problematic conflation that disregards the complexities of intergenerational transmission, according to Fortunato. Early anthropologists linked matriliny to matriarchy, and because of the conflation,

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SNAPSHOTS FROM THE 2019 SFI SUMMER SCHOOLS *Clockwise to center: CSSS students in the Noyce; GWCSS student Ketika Garg and Professor John Miller discuss an idea; REU Jacob Jackson at work; CSSS students explore the Simtable; REUs Shaili Mathur, Aram Moghaddassi, and Gabriel Goren play foosball; Panelists External Professor Luís Bettencourt, Santa Fe Mayor Alan Weber, and Matt Petersen of the Los Angeles Cleantech Incubator at GSSS; Kirbi Joe, Therese Bennich, Aviva Blonder, and Ketika Garg in the Gatehouse; Kyle Furlong and Robert Coulter (CSSS) in the Noyce; Bhargav Srinvasa Desikan, Aabir Abubaker Kar, and Kate Wootton (CSSS) in the Atrium; Alec Kirkley and Hunter Wapman (CSSS) in Pod B; M. Koissi Savi (CSSS) in Pod A; Luther Seet and Kazuya Horibe (CSSS) on the Noyce Portál; GWCSS students at the Gatehouse; Anshuman Swain and April Kleppe (CSSS) window writing. (Photos by Douglas Merriam and Laura Egley Taylor)*

Fall 2019

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THE NEWSLETTER OF THE SANTA FE INSTITUTE

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Summer in the rearview

2019 SFI summer schools

SFI's "social reactor" kicked into overdrive this summer, welcoming 163 undergraduates, graduate students, and professionals. Intensive summer programs form the core of the Institute's educational programming, bringing future complexity scholars to Santa Fe to train with leading scientists.

This year, the **Graduate Workshop in Computational Social Science and Complexity (GWCSS)** celebrated its 25th anniversary with programming for alumni as well as a new cohort of advanced graduate students.

The flagship **Complex Systems Summer School (CSSS)**, now in its 31st year, returned to the campus at the Institute for American Indian Arts to tour complex behavior in mathematical, physical, living, and social systems.

In partnership with the University of Chicago's Mansueto Institute for Urban Innovation, SFI hosted a two-week **Global Sustainability Summer School (GSSS)** to explore how the battle for sustainable development can be won in cities by kick starting "virtuous cycles" of improvement.

And the NSF-funded **Research Experience for Undergraduates (REU)** program paired a dozen undergrads with SFI mentors to develop research projects of their own choosing. At the end of their 10 weeks, they presented their work on topics as varied as the origins of agriculture, vaccine hesitancy, paleolithic climate, and associative memory.

Read more about our annual summer programs at santafe.edu/schools.

RESEARCH BRIEFS, *continued from page 3*

reached problematic conclusions. "Matriarchy was seen as the 'primitive' form," Fortunato says, "and then eventually there's a transition to the 'advanced' form which is the patriarchy." Fortunato suggests terminological specificity as a first step in revamping our understanding of how power and resources move through generational time.

INEQUALITY'S ORIGINS

Seven thousand years ago, societies across Eurasia began to show signs of lasting divisions between haves and have-nots. In new research published in the journal *Antiquity*, SFI External Professor Amy Bogaard, Professor Sam Bowles, and economist Mattia Fochesato of Bocconi University chart the precipitous surge of prehistoric inequality. In the first of two companion papers, the researchers present new statistical methods for comparing wealth inequality across different kinds of wealth, different societies, in different regions, at different times in history. Their analysis of data from 150 archeological sites reveals a steep increase in inequality in Eurasia from around 4,000 BC.

Why very egalitarian farming economies persisted well into the Neolithic, at least four millennia after the advent of farming, will be explained in their second, forthcoming paper (also in *Antiquity*). The work results from Bowles' long-running series of interdisciplinary workshops on the origins of wealth inequality, which convene annually at SFI.