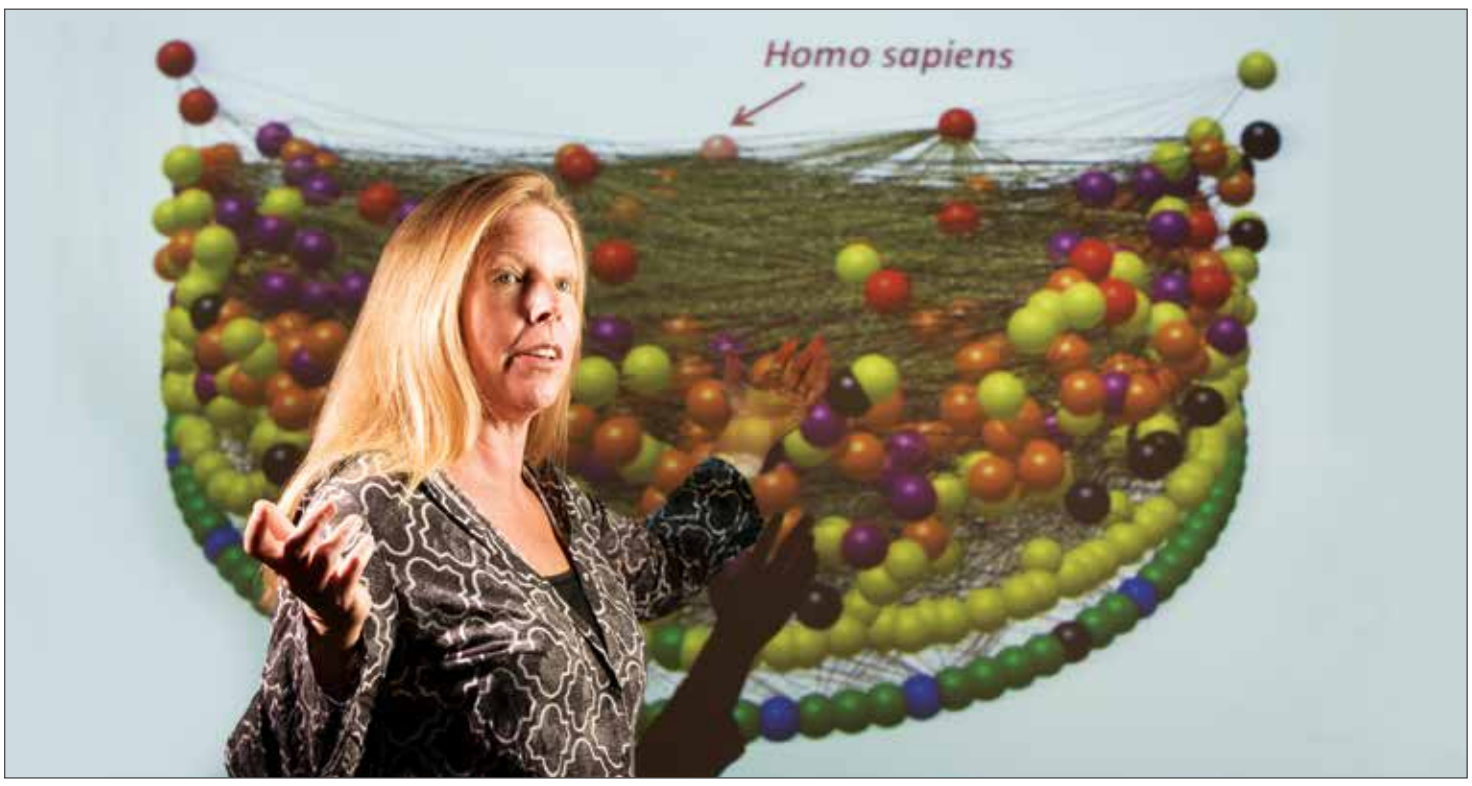
Winter 2018–19

Parallax

THE NEWSLETTER OF THE SANTA FE INSTITUTE



Jennifer Dunne presents her Sanak Nearshore food web. With 513 species and ~6800 feeding links, it is the first detailed, complex food web to explicitly include humans.

Two AAAS sessions trace humanity's place in the web of life

Traditional images of food webs depict a diverse set of species, from plants and herbivores to predators and parasites, with directional lines of interaction — who eats whom. Despite a growing awareness that humans are intrinsically linked to our environments and ecosystems, we rarely show up on these datasets, images, or analyses.

SFI Vice President for Science and Professor Jennifer Dunne and visiting researcher Stefani Crabtree, a Fellow at the Center for Research and Interdisciplinarity in Paris, France, have been working to understand how humans across the globe utilized other species in the past, not just through feeding but through myriad other interactions.

Their ArcheoEcology Project is the first to compile this kind of comprehensive data from multiple pre-modern cultures to figure out how humans fit into and impacted complex ecological networks.

Dunne, Crabtree, and their colleagues will present their work in two back-to-back symposia, "How Human Interactions with Biodiversity Shape Socio-Ecological Dynamics in Deep Time" on Sunday, Feb. 17 at 1:30 and 3:30 pm at the American Association for the Advancement of Science meeting in Washington, D.C.

The talks and presentations will cover new results from five well-studied systems including aboriginal foragers in Australia, ancestral Puebloans in the American southwest, First Nations people of the Pacific Northwest coast, South Pacific island Polynesians, and North Atlantic island Norse people. By integrating and exploring a large body of anthropological and archaeological knowledge about past systems where we know socio-ecological trajectories and outcomes, we can better understand commonalities and differences in a coupled natural-human systems' resilience, sustainability, and robustness.

SFI announces two new Miller Scholars for 2019

Historian Andrea Wulf and philosopher John Kaag have been named Miller Scholars at the Santa Fe Institute for 2019. The Miller Scholarship is the most prestigious visiting position at SFI, awarded to highly accomplished, creative thinkers who make profound contributions to our understandings of society, science, and culture.

Wulf is an award-winning author of five books. Her latest, *New York Times* best-seller *The Invention of Nature*, published in 2015, delves into the life of German naturalist Alexander von Humboldt, whose travels and insights revealed similarities in ecosystems around the world, predicted human-induced climate change, and spawned the modern environmental ethic. It's published in 26 countries and won fourteen international awards. Her forthcoming book, *The Adventures of Alexander von Humboldt*, is a graphic non-fiction book which will be published by Pantheon in spring 2019.

She has written for *The New York Times*, *The Atlantic*, the *Los Angeles Times*, the *Wall Street Journal*, and other publications. Wulf is a three-time fellow of the International Center for Jefferson Studies at Monticello and the Eccles British Library Writer in Residence 2013. She's a member of PEN American Center, an International Fellow of the Explorer's Club, a member of The Society of Woman Geographers, a Fellow of the Linnean Society, and a Fellow of the Royal Geographical Society.

Kaag is the acclaimed author of six books that explore his wide-ranging interests, from drone warfare to the origins of the imagination to the intellectual history of thought and the evolution of ideas. His book *American Philosophy: A Love Story* was a *New York Times* Editors' Choice, a 2016 NPR Best Book of the Year, and the recipient of the 2018 John Dewey Prize for Best Book in American Intellectual History.

> MORE ON PAGE 3

Big data meets a radical new definition of cell type

Biologists have long sought to understand human cells, and in recent years, tools like high-throughput genetic sequencing have afforded unprecedented access to the underlying molecular machinery. Those efforts have produced a torrent of data in a brief amount of time. In response to that surge in cell sequencing, researchers have launched large-scale efforts to collect those data including the Human Genome Project, the Human Cell Atlas, and the Human Protein Atlas.

Those projects need something besides terabytes: A fundamental framework that can connect them all.

"Without a proper theoretical understanding, they are confronting this deluge of data without a meaningful way to organize it," says biologist and SFI External Professor Manfred Laubichler (Arizona State University).

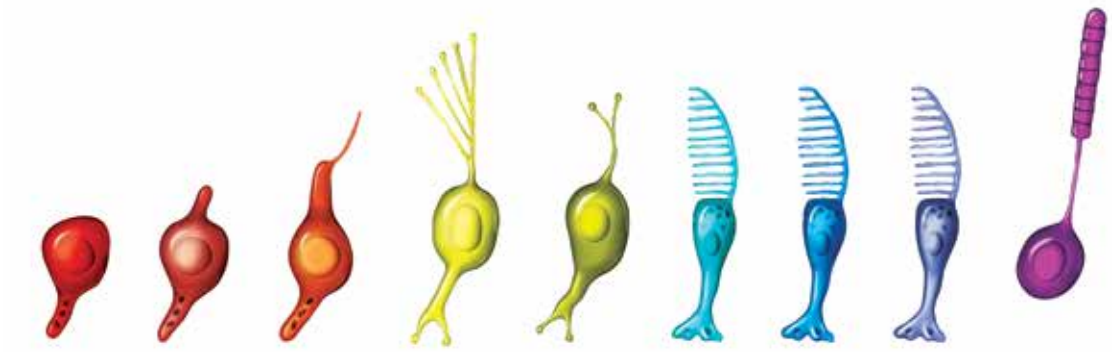
Two years ago, Laubichler helped organize an interdisciplinary SFI working group that over the course of a few days developed a radical new organizational structure for cell types. Instead of categorizing cells by phenotypes, or observable features, the researchers grouped cell types along new conceptual lines. They proposed grouping cells together according to their shared evolutionary history, and by identifying the molecular agents that determine the ultimate fate of a cell.

The meeting led to a pivotal paper published in *Nature Reviews Genetics* in 2016. Now, it's inspired a second working group, to be held in March at SFI, designed to put those conceptual ideas to work. Participants will include the biologists and physicists who helped develop the original idea, as well as data-driven scientists engaged in big data efforts like the Human Cell Atlas.

"We're bringing new people into the SFI orbit," says Laubichler.

The working group has two main goals. First, they want to hammer out a better understanding of the formal framework proposed in the *NRG* paper. Second, they want to produce a functional model that embodies the proposed new concept of cell types. Data scientists might use such a model to analyze sequencing data to identify patterns and connections among cell types based not on appearance, but instead on shared evolutionary history.

Such a model, says Laubichler, would bring organization and structure to those ongoing projects. "We want to operationalize the concept so it becomes useful for all those large-scale efforts," he says. "This is quite an urgent and important thing to do at this stage."



At left: Photoreceptor cells. (Image: Mesa Schumacher)

BEYOND BORDERS

COMPLEXITY & UNIVERSALITY

Science strives to explain the world through elegant and judicious exposition. And the hallmarks of good science have always consisted in some combination of coverage (the breadth of phenomena encompassed), minimalism (the efficient encoding of observation), naturalness (appealing to the mind and connecting to existing ideas), and predictive power.

The domain of complexity science might seem on the surface to be one that controverts these characteristics: system-dependent, maximal, unnatural, and contingent. And over the years I have certainly met many who derive a mild pleasure, let's call it an epistemological *schadenfreude*, from all of those failed efforts to apply to complexity the wrecking ball of physical theory with all of its symmetries, equalities, laws, and "back of the envelope" hubris.

And while it certainly could be true that the human imagination has more than met its match in complexity, such that for certain phenomena it is appropriate to forgo understanding in favor of over-sized models and simulations in order to better predict (as we routinely do with weather forecasting) , I do not believe that it is time to throw in the towel.

In his wonderful essay, "Nature conformable to herself" Murray Gell-Mann builds on Isaac Newton's insight into the "consonance" or "conformability" of nature, whereby the same laws apply at many different scales.

Murray writes "As we peel the skins of the onion, penetrating to deeper and deeper levels of the structure of the elementary particle system, mathematics with which we become familiar because of its utility at one level suggests new mathematics, some of which may be applicable at the next level down — or to another phenomenon at the same level. Sometimes even the old mathematics is sufficient."

Murray points out that conformability is in large measure the key to the utility of parsimony. This is because the frugality of nature permits a prudence of mind. And over the last few decades multi-scale general patterns have been observed across a large swathe of complex systems, from the networks governing metabolism up through ecologies and cities—all promoting advances in theory development.

After thirty years pursuing areas in which complexity might be approached through the lens of simplicity, the Santa Fe Institute is teaming up with the National Science Foundation to explore via a meeting on "Convergent Paths towards Universality in Complex Systems" at the end of May in Washington D.C.

This is a very exciting meeting as it represents a summa and a summary of SFI and affiliated research work across a range of areas including Information Processing Systems; Adaptive Dynamics; Regularities in Ecology; and Scaling in Biological and Urban Systems. In each of these areas we shall be exploring how far the community has progressed towards universality — principles that transcend mechanism, scale and history — and discussing the long-term prospects for intervention and thoughtful management of complex systems. This event is also timely as it brings SFI to Washington at a moment when rational discourse and collaboration are more important than ever.

— David Krakauer
President, Santa Fe Institute

CREDITS

EDITOR: Jenna Marshall

CONTRIBUTORS:
Sam Bowles, Natalie Elliot, Dave Feldman, Lucy Fleming, Katherine Mast, Stephen Ornes, April Reese, Linden Schneider, Emily Schwend, Paul Stapleton

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.

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ACHIEVEMENTS

Frances Arnold, who served on SFI's Science Board from 1995-2000, received a Nobel Prize in Chemistry in October 2018. Arnold is a professor of chemical engineering, bioengineering, and chemistry at Caltech, and was selected for her pioneering work begun in the early 1990s on directed evolution in enzymes.

Shannan Distinguished Professor and Past SFI President **Geoffrey West** was awarded the 2018 Los Alamos Medal by Los Alamos National Laboratory for renowned work in scaling theory. West founded the Lab's high-energy physics group in 1974, and went on to lead the Cities, Scaling, and Sustainability group at SFI.

R&D Magazine selected former SFI External Professor **Bette Korber** to receive their Scientist of the Year Award for 2018, recognizing her evolution-inspired approach to developing an HIV vaccine. Korber, a theoretical biologist at Los Alamos National Laboratory, has spent more than 25 years studying ways to create a globally effective HIV vaccine.

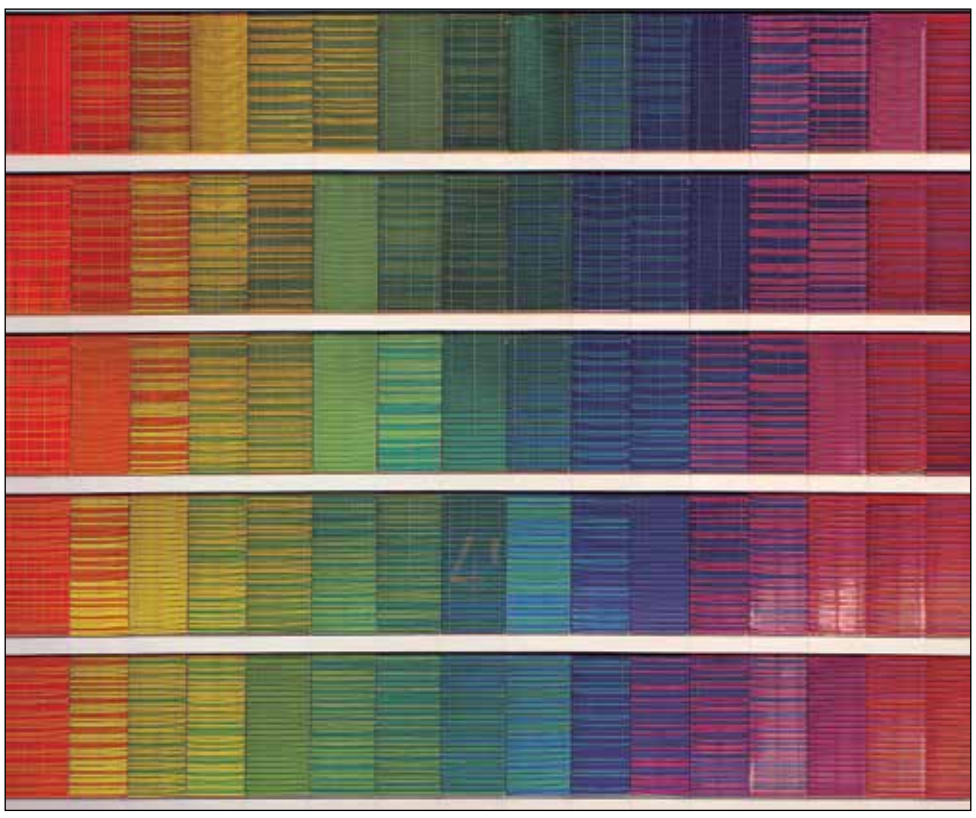
Working group: Thinking along the spectrum

"Categorization makes it easier for people to think about things. We only have so much mental capacity."

—VICKY CHUQIAO YANG, SFI OMIDYAR FELLOW

We think of colors as absolutes: Red is red and yellow is yellow. But colors exist on a spectrum, and the lines between them are not quite so distinct. This tendency to oversimplify distinctions shows up in politics as well: While we tend to slot people into one political party or another based on their political views, that label often fails to capture the nuances of individual experience that shape voter behavior.

How did we come to parse the world around us into such neat categories, and what are the costs and benefits of these labels? How do categories change and evolve over time? Over three days in March, a diverse group of researchers, including a sociologist, physicist, biologist, and mathematician, will gather to explore these questions. The working group will use an unusual mix of computer modeling and human experiments to get at the answers. For example, the researchers will employ machine learning to determine how a computer processes information that's on a spectrum, and compare that with how humans do the same thing.



Color spectrum (Image: Ricardo Gomez Angel)

"We are trying to understand why we tend to create categories for things in our everyday life (colors, gender, political group) even if in reality these things are on a continuous spectrum," says Tamara van der Does, a Postdoctoral Fellow at SFI. "Specifically, we want to look at what are the benefits of categorizations (and of more or less categorizations) and when do categorizations emerge."

"The categorization makes it easier for people to think about things. We only have so much mental capacity," explains Omidyar Fellow Vicky Chuqiao Yang, the working group's organizer. She adds that the group's work "is about understanding where it comes from and understanding how that may change. I think that may help us as the world grows more diverse."

Gaining a better grasp of how people categorize phenomena is especially useful in today's deeply partisan political climate, she says. "I personally think the 'us versus them' mentality has been growing in recent years."

The working group, which grew out of an informal "research jam" at the Sept. 2018 James S. McDonnell Foundation-SFI Postdocs in Complexity Conference IV (at SFI) , will be held March 18-20.

Complexity postdocs to convene fifth joint conference

Research jams, intercontinental collaborations, and lightning talks — the Postdocs in Complexity Conference is back!

Now in its fifth incarnation, the twice-yearly conference brings SFI's postdocs together with James S. McDonnell Foundation (JSMF) postdoctoral fellows based at institutions across the world. The upcoming meeting will take place March 12–15.

"All the conferences have focused on building a network of early career complex systems scientists and developing collaborative relationships," says Hilary Skolnik, Program Manager of the Postdoctoral Fellows Program. "Now, many of those conversations have borne fruit. We actually have three working groups at SFI this winter that emerged from past conference Research Jams."

One such brainchild is the Sociality Under Scarcity working group led by SFI Omidyar Postdoctoral Fellows Albert Kao and Joshua Garland (see page 4).

"Both the JSMF and SFI have been really responsive to the feedback that the postdocs have given after each conference, and one consistent request has been for more space and time for more constructive interactions and collaboration," says Kao. "I think that these workshops are the first time that JSMF and SFI postdocs have had the chance to collaborate on real, meaningful research projects together, and I'm really excited about that."

In March, JSMF Fellows Allison Barner and Lauren Shoemaker will explore integrating species competition and network theory (see page 3), while SFI Omidyar Fellow Vicky Chuqiao Yang will lead a group investigating the costs and benefits of categorization (see page 2).

SFI President David Krakauer addresses participants at the fourth JSMF-SFI Postdoctoral Conference at Monolith Beta on the Cowan campus in September. (Image: Laura Egley Taylor)

The JSMF–SFI partnership unites thinkers even within the same field. Barner and Shoemaker, for example, both nominally work in the field of community ecology, but come at it from different angles. Says Barner, "We met during the joint JSMF-SFI Postdoc in Complexity Workshops, and over repeated conversations came to the conclusion that there may be some simple steps to unify these different perspectives."

"There is something highly complementary about the complexity postdocs that are dispersed throughout the country — or the world — and those that are housed in a particular place at Santa Fe," says Kao. As the global JSMF–SFI community descends on Santa Fe this spring, sparks may already be flying for collaborations in years to come.

At left: Sea anemones from the 49th plate of Kunstformen der Natur (Image: Ernst Haeckel, 1904)

Working group aims to bridge two theories of biodiversity

From the Amazon rainforest to the Arctic tundra, the world's ecosystems host unique biological communities that have evolved and diversified over millennia. Since the 1970s, community ecologists have relied on two theories to explain the role that species interactions play in this astonishing biological diversity: coexistence theory, which maintains that competition among species for resources is the driving force; and food web theory, which argues that dependence, such as a predator's reliance on prey or a pollinator's reliance on nectar, is the prevailing influence. While both theories emphasize species interactions, there's been surprisingly little effort to integrate them.

Hoping to build a bridge between the two theories, Lauren Shoemaker and Allison Barner — both James S. McDonnell Foundation Fellows involved in the JSMF-SFI Postdocs in Complexity Conferences — organized a new SFI working group, which will meet March 7-11. The group, which emerged out of a research jam at the fourth conference, will use data from marine ecosystems, where species interactions are well studied, to explore how elements of the competition and food web theories might be combined to create a fuller picture of the forces shaping biodiversity at the community level.

"It's saying, 'what happens when we look at this holistically?'" Shoemaker says.

"Ideally, we'll develop a theory that can apply across ecosystems," Barner adds.

The group is diverse, with researchers from fields ranging from molecular biology to fisheries biology to computer science. "One really exciting part of this working group, and SFI more generally, is it's so unique in bringing together people of different backgrounds," Shoemaker says. "We're bringing in people from other disciplines to help us think about ecology in new ways."

Which ecosystem changes can be reversed?

Across the world's ecosystems, from the boreal forests of North America to the savannas of Africa, a host of animals and plants constantly interact: predators fell prey, insects devour plants, epiphytes perched high in their host trees draw moisture from the air. All of these interactions influence animal and plant populations in myriad ways, but researchers are still trying to understand the complex dynamics. A working group to be held January 29-31 will look at the consequences of the changes in interactions between species — especially how these changes lead to irreversible transitions in the structure and composition of ecological communities.

"Most of the models and most of the theory in ecology is based on the assumption that interaction between species are constant, at least on the timescale we're observing the dynamics in the community," says Omidyar Fellow Jacopo Grilli, who is organizing the working group with Dervis Can Vural of the University of Notre Dame "On the other hand, there are changing factors — species are evolving and also changing their behaviors. So, if you're a predator, you might switch prey for example. We're looking at how interactions are changing, and how the community changes as a result — and how much the changes in the community are reversible."

Some of the questions the group will explore are: How do interactions between two or more species change over time? How do species interactions lead to ecological transitions? How can ecosystems be fortified against catastrophes? This information could aid conservation efforts — for example, to help determine whether extinction of a species in a particular area could be reversed through reintroduction or colonization by members of other surviving populations.

The working group,which consists of ecologists, physicists, and experts in network theory, is a part of the Aging, Adaptation, and Arrow of Time research theme funded by the James S. McDonnell Foundation.

Trocadero Marbella Rugby Club, Marbella, Spain (Image: Quino Al)

Fight or cooperate? Working group to study dynamics of sociality, decision-making, and information

In social species like humans, the information we have about group members and the nature of their relationships can help us make decisions about how to interact with each other. This process impacts our decisions about whom to fight and when to cooperate. Scientists have studied aspects of how people process information in social situations through controlled lab experiments. However, to more comprehensively understand the interplay of sociality, decision-making, and information, we need more complex models that incorporate dynamics of real-world interactions.

A working group meeting February 4-6 will begin to develop a generalizable theory about the role of information in group conflict. The meeting is part of a grant from the Army Research Office, funding a project led by SFI External Professor Simon DeDeo (Carnegie Mellon), ASU-SFI Fellow Elizabeth Hobson, and Dan Mønster, Associate Professor at Aarhus University and a recent sabbatical visitor at SFI.

At the heart of their project is a networked computer game, developed by Mønster. As people play the game in the lab, the team can adjust the amount and type of information each player receives about others, and monitor how every individual's decisions change in relation to the information they have. The researchers detect signatures of these decision-making processes using new computational tools.

The working group will bring together researchers studying how sociality and cognition interact in both humans and animals. "It's a large group of researchers including people from sociology, anthropology, psychology, social evolution, and others," says Hobson. "We want to find new areas of commonality that would tie our work more closely to the work in these other fields."

Participants sit for an experimental session at the Cognition and Behavior Lab at Aarhus University, where Mønster has tested his networked computer game. (Image: Aarhus University)

The team hopes the working group will develop new connections for linking lab results and real-world data and identify other systems in which networked computer games may be useful for understanding social decisions.

"In the real world, we're faced with lots of information that could be used to make decisions" says Hobson. "This project could give us insight into how we process that information, and the cognition behind it."

2019 Miller Scholars *(cont. from page 1)*

The sequel to *American Philosophy*, entitled *Hiking with Nietzsche*, was published to critical acclaim in 2018 and was also named a Best Book by NPR for the year. In this work, Kaag blends personal memoir with meditations on classical philosophers to uncover the wisdom within their writings and apply it to 21st-century dilemmas.

Kaag has written for *The New York Times*, *The Wall Street Journal*, *Harper's Magazine*, and the *Paris Review* among others. He is the current Chair of the Philosophy Department at the University of Massachusetts Lowell. He has held academic fellowships at the Harvard Humanities Center and the American Academy of Arts and Sciences.

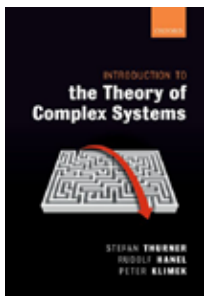
"We are delighted that John Kaag and Andrea Wulf will be joining us as new Miller Scholars in 2019," remarks SFI President David Krakauer. "Both John and Andrea work outside of the quantitative natural sciences, yet their work focuses on individuals and communities that overlap in considerable and deep ways with the ambitions and philosophy of the community of the Santa Fe Institute. SFI benefits enormously from thinkers like Andrea and John who make the life of the mind their focus, helping us to better understand the broader currents moving and molding our intellectual pursuits, and by bringing a true diversity of thought into our daily lives and conversations. Andrea and John will be joining existing Miller Scholar Laurence Gonzales, who is finishing up his historically situated inquiry into the unique culture and personalities of the Santa Fe Institute."

New SFI Miller Scholars Andrea Wulf and John Kaag

Scholars are internally nominated and may have backgrounds in the humanities, arts, or sciences. During their stay at SFI, Miller Scholars are free to devote their time to scholarship on any topic. They are encouraged to interact and collaborate with resident and visiting scientists, with the goal of catalyzing and crystallizing ongoing research at SFI.

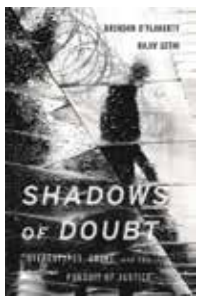
Wulf and Kaag will reside at the Institute part-time in 2019, as the ninth and tenth Miller Scholars since SFI Chair Emeritus Bill Miller conceived and underwrote the scholarship in 2010. They join author Laurence Gonzales (2016-2019) and follow philosopher and biographer Ray Monk (2017), author Neal Stephenson (2015-2016), author Hampton Sides (2015), actor-author-playwright Sam Shepard (2012-2013), philosopher Rebecca Goldstein (2011-2012), philosopher Daniel Dennett (2010), and quantum mechanic Seth Lloyd (2010).

New books by SFI authors



Introduction to the Theory of Complex Systems (Oxford University Press, 2018) by SFI External Professor Stefan Thurner and his colleagues Rudolf Hanel and Peter Klimek at complexity Science Hub Vienna, synthesizes hundreds of findings to distill what complex systems share in common. This rigorous, introductory textbook offers a comprehensive overview of complex systems, from ecosystems and traffic to financial markets and social media, and the tools needed to understand their co-evolutionary natures.

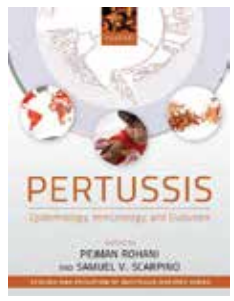
The Model Thinker: What you need to know to make data work for you (Basic Books, 2018) by SFI External Professor Scott Page simply and in clear language describes dozens of models that can help readers better understand the world. The "many-model thinking" approach offered in the book shows how the insights and overlap of different approaches produces wisdom and more nuanced understandings of complex phenomena.



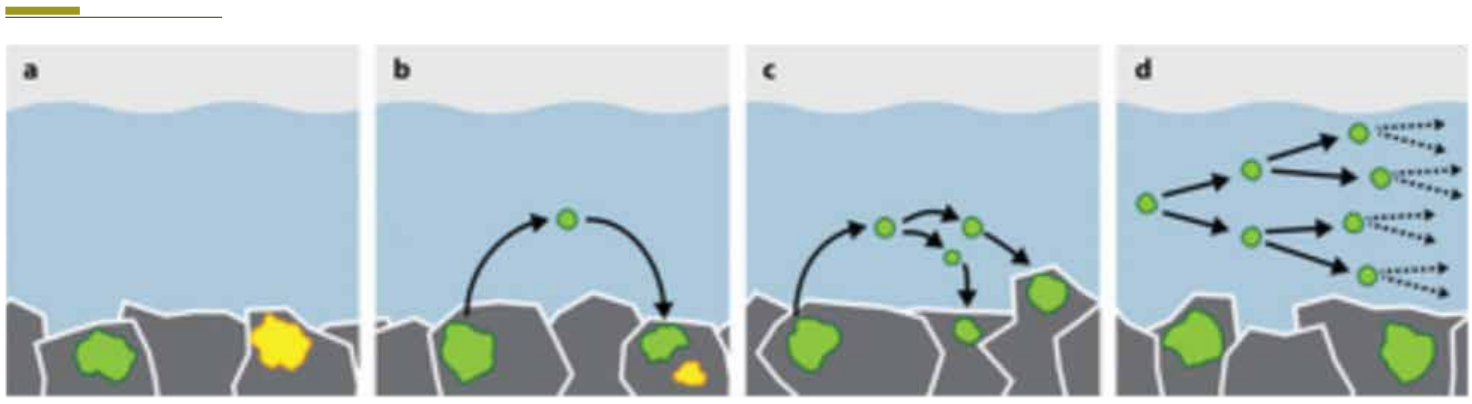
Shadows of Doubt: Stereotypes, Crime and the Pursuit of Justice (Harvard University Press, 2019) by SFI External Professor Rajiv Sethi and Brendan O'Flaherty explores how stereotypes impact the way crimes unfold, and how they contaminate the justice system. At every step in a crime and its punishment, offenders, victims, law enforcement, and jurors make high-stakes decisions with imperfect information. Stereotypes provide deceptive and powerful shortcuts in time-sensitive decision-making and are implicated in the most controversial criminal justice issues of our time.

Computational Matter (Springer International Publishing, 2018), edited by SFI External Professor Steen Rasmussen, Susan Stepney, and Martyn Amos and part of the Natural Computing series, offers an overview of computing *in materio* -- the unconventional computing performed by directly harnessing the physical properties of materials. This introductory text book provides an overview of the field, with particular attention to theory, practice, applications and implications.

Viruses as Complex Adaptive Systems (Princeton University Press, 2019), by SFI External Professors Ricard Solé and Santiago Elena, examines viruses as both infectious parasites and drivers of species evolution. Pairing complex systems theory with an understanding of viral dynamics has offered new insights into how AIDS develops in patients with HIV-1 and how the flu evolves, and the authors show how it can also be applied analogously to other replicators like computer viruses, cancer, and languages.



Pertussis: Epidemiology, Immunology, and Evolution (Oxford University Press, 2019) edited by former SFI Omidyar Fellow Samuel Scarpino and Pejman Rohani, offers a comprehensive overview of the current scientific and public health knowledge of pertussis, or whooping cough, which is one of the world's leading vaccine-preventable killers. In many regions, including the U.S. and Europe, pertussis cases are on the rise, and there is not consensus as to why. This volume gathers chapters from disparate fields to provide a synthesis of what is known.



The evolution of cells from surface-bound protoplasm. (Image: David Baum, BioScience 2015)

New course to guide learners through 'unsettled' research at life's origins

This summer, SFI's online education platform, Complexity Explorer, will offer its first course based on "unsettled" research. The new course, "Origins of Life," will be taught by mathematical biologist and SFI Professor Chris Kempes, and Sarah Mauer, Associate Professor of Chemistry and Biochemistry at Central Connecticut State University.

"This course is unlike anything we've offered before on Complexity Explorer," says Linden Schneider, SFI's Online Education Coordinator. "Chris and Sarah's course aims to take a wide-reaching and unsettled area of research and present it to a wide audience."

Current courses on the platform cover well-established, foundational areas and methods for complexity science, such as nonlinear dynamics and chaos, agent-based modeling, and fractals and scaling. Origins of Life, however, emerges from an active Research Coordination Network (RCN) funded by a National Science Foundation grant on which Kempes and SFI President David Krakauer are co-principal investigators. Their project aims to push the field forward by bringing new and synthetic thinking to the question of how life emerged from an abiotic world.

Like the Santa Fe Institute, the study of life's origins is highly interdisciplinary. But it's "interdisciplinary where we don't yet know how the disciplines will be put together," Kempes explains. "We generally know what chemistry to teach medical doctors or what physics to teach engineers, but in the origins of life, this is not the case at all."

The RCN connects scientists from many different disciplinary backgrounds, as well as those from different "camps" in the study of origins of life, such as those who focus on RNA and those who focus on geo-microenvironments as the key to unlocking the secrets of life's beginnings. This diversity of backgrounds and foci will be represented in the online course, as many of the RCN members have filmed guest lectures.

The course will walk students through this active area of research by exploring topics such as the evolution of intelligence, information transmission in chemical systems, and questions including whether life is an easy or hard process and what aspects of extant life are arbitrary.

According to Schneider, one of the long-term aims of the course is to "draw new minds to the field, as Origins of Life is not a traditional discipline of study."

The Origins of Life course will be free and open to all through Complexity Explorer, SFI's online education portal at www.complexityexplorer.org

Working group: What drives the natural response to scarcity?

Faced with a food shortage, every living thing has to decide what to do to survive. Strategies vary by species. Some lions and primates become less social during scarce times. Other critters, like locusts, slime molds, and bacteria, are more likely to band together. Scientists don't have a solid understanding of the costs and benefits of these choices, or the environmental situations in which they're most likely to arise.

Identifying the mechanisms that drive these social responses is the goal of a working group that will gather in Santa Fe over five days in February. SFI Omidyar Fellows Joshua Garland and Albert Kao are co-organizing the meeting. Participants will first conduct a review of relevant studies, then will collaborate on creating a model to allow researchers to conduct simulations to test new ideas about the effect of scarcity on sociality.

Garland says understanding these behaviors is inherently an interdisciplinary problem. "You need experts in animal species and ecology who've done experimental work, and you need mathematicians and physicists who understand how to model a system."

Biological observations will drive the design of the model, and the model will in turn help scientists gain insights into rules and trade-offs that might be operating in nature, says field biologist and participant Amanda Hund, a James S. McDonnell Foundation Fellow at the University of Minnesota. "The whole goal is that it's a circle," she says. Researchers can return to the field to run tests and gauge how well experimental and predicted data align.

The idea for the working group grew out of an informal "research jam" at the Sept. 2018 James S. McDonnell Foundation-SFI Postdocs in Complexity Conference IV. Kao and Garland wanted to capitalize on the energy from that meeting and build on a broad base of expertise in biology, ecology, complexity, mathematics, and information theory. Instead of meeting on campus, the eight SFI and JSMF Postdoctoral Fellows will move into a rental house near the Institute. The goal of that format, says Garland, is to promote deep interdisciplinary connections that will last beyond the working group.

The idea for the working group grew out of an informal "research jam" at the Sept. 2018 James S. McDonnell Foundation-SFI Postdocs in Complexity Conference IV.

Death as a system collapse

All multicellular organisms senesce and eventually die. So, too, with most biological systems — whether mitochondria, or hearts, or dogs, or any of the ecosystems that living things inhabit.

According to SFI External Professor Michael Hochberg, Director at the Center National de la Recherche Scientifique at the University of Montpellier, we see biological death more clearly when we understand it in terms of system collapse. Imagine a doctor who attributes her patient's death to heart failure. What if the deceased, who was eighty-five, also had pneumonia and had recently broken a hip? How do these latter facts enter into our understanding of the cause of death?

Understanding the patterns of mortality, biological failure, and system collapse is the focus of a forthcoming working group at SFI, "Hallmarks of Biological Failure," which will take place April 8-10. Hochberg, along with Daniel Promislow, have planned three meetings on the subject. In the first, this April, they will convene a group of researchers to take stock of theories and data across disciplines on the structures of biological failure from a non-evolutionary standpoint. In the second, they plan to bring these patterns into an evolutionary framework — how does evolution shape the patterns of aging? In the third, they will consider the possibility that patterns in the collapse of biological systems are similar to those of non-living systems.

The organizers expect that the ongoing working group will bring into relief the universal patterns of senescence that researchers see in biology, gerontology, and evolutionary biology — and therefore have a bearing on a wide range of applied fields, including human health, species conservation, and pest control. For Promislow, the group may deepen the theoretical framework for his large-scale work on aging dogs at the Canine Longevity Consortium. Since dogs are the most phenotypically variable animals, comparing their aging processes across breeds will help researchers illuminate and sharpen patterns of the kind that the working group will explore.

In the long term, Promislow and Hochberg will investigate whether their work will yield insights into the ways that non-biological systems collapse. Does the collapse of a galaxy or the failure of a circuit board bear any resemblance to the collapse of an ecosystem or a heart? Promislow and Hochberg hope, cautiously, that the new wave of systems level work in biology they are undertaking will yield fascinating insights into patterns of collapse in systems of all kinds.

The working group is a part of the Aging, Adaptation, and Arrow of Time research theme funded by the James S. McDonnell Foundation.

SFI IN THE NEWS

In an October 4 Observation for *Scientific American*, SFI Professor **David Wolpert** wrote that computers could be vastly more efficient if only we better understood the thermodynamics of computation. *Wired* picked up the thread, mentioning Wolpert's post in a December 12 story about undersea data servers.

The Canadian Broadcasting Company featured research co-authored by External Professor and Science Board member **Jessica Green** in a December 12 story about antibiotic resistance emerging at gyms.

The Hidden Forces Podcast spoke with 2011 Miller Scholar **Rebecca Goldstein** about the importance of asking big, unquantifiable questions.

SFI got a shout-out in a December 4 *Nature* article reviewing the book *Laboratory Lifestyles* and its claims that luxe labs spark discovery.

Forbes profiled former SFI staffer **Elizabeth Martinez Archuleta** in a series about how technology is empowering better work-life balance and flexibility.

The Verge includes a quote from External Professor and Science Board member **Barbara Grosz** in its review of the book *Architects of Intelligence* and the varied perspectives from top researchers about when artificial general intelligence might be achieved.

A *Bloomberg* excerpt of the book *The Myth of Capitalism* mentions Professor **Geoffrey West's** work relating scaling laws in the biological world to growth patterns of companies.

In a November 28 article, Vox featured External Professor **Jessika Trancik's** new research on the plummeting cost of solar panels. The work was also mentioned in *The New York Times*.

Why are young people having so little sex? In their December issue article on courtship in the modern recession, *The Atlantic* referenced a recent study by External Professors **Elizabeth Bruch** and **Mark Newman** about online dating.

Bloomberg took a look at voting predictions, highlighting Professor **Mirta Galesic's** work on better polling through questions about how a person's friends plan to vote.

SFI Chairman of the Board **Michael Mauboussin** gave a shout-out to SFI in an interview published November 5 in *Forbes*.

Search and decide: ACtioN meeting explores how human search strategies are evolving

Like other species, we humans search for the resources we need and want. We sort through information to find food, shelter, jobs, and romantic partners. Through much of our evolutionary history, we searched in environments of scarcity, and we needed strategies to gather costly information.

Now, we have access to overwhelming amounts of information. We need strategies to sort through the abundance.

"There is a lot of work on foraging and search in other animals, but it's hard to study empirically in humans," says External Professor Elizabeth Bruch (University of Michigan), who has analyzed data from online dating sites to study how people search for mates through the internet.

Bruch is helping to coordinate an upcoming SFI ACtioN meeting to explore how organizations can benefit from research into people's modern search and decision-making processes. Also of interest is how academics could benefit from the troves of data being collected by firms, government agencies, and other NGOs.

The meeting, which will be held April 25 at Google Venture, will bring together an eclectic group of academics and business people, from people who study ancient forms of navigation, to those looking at outer space exploration, to those involved in searches for housing and partners.

"I study human behavior as observed in online environments," says Bruch. But that work is only possible through partnerships with the companies who own the data. "As a researcher, I can collect data, but it's hard to replicate the natural environment of 4 million people using a dating site."

That access to data can help social scientists better understand how people make different types of decisions; if a search for, say, housing looks different from a search for mate; and if a person in a large city chooses a different strategy from someone living in a smaller town.

"In these proprietary data sets, we can see everything that is logged," says Bruch. "You see the searches that didn't work, and you can see how people revised to find a successful search."

The meeting will bring together an eclectic group of academics and business people, from people who study ancient forms of navigation, to those looking at outer space exploration, to those involved in searches for housing and partners.

These collaborations have a practical application, too: companies operating search engines or dating websites could help people find what they're looking for if they had a better understanding of how humans search and how our search process is evolving.

"New datasets generated by online searches are re-energizing this area of study, but search has always been an important component aspect of complexity science," says Will Tracy, VP for Applied Complexity. "This meeting should be useful for both SFI scientists interested in search, and ACtioN members whose operations are being impacted by new forms of online search. Ideally, some of the themes introduced in this meeting will be further developed in the Complexity of Retail ACtioN meeting planned for summer 2019 and the November Symposium on New Complexity Economics."

More information about this and other upcoming ACtioN meetings can be found at santafe.edu/AppliedEvents

Toward "A new paradigm for political economy"

Neither Nordic social democracy nor Thatcherite and Reaganite neo-liberalism offer a set of political, economic and philosophical principles adequate to the challenges of populism and xenophobic nationalism, according to frequent SFI visitor Wendy Carlin of University College London and SFI Professor Samuel Bowles. Moreover, they point out, these models of public policy are out of step with recent research developments in their field: notably in the economics of information and behavioral economics.

This February, Carlin and Bowles will host a small working group at SFI to outline possible new directions for research at the interface between economics, public policy, and philosophy. The meeting will further develop themes in from their well-received SFI Community Lecture in July of 2018 titled: "After Trump and Brexit: A New Economics (forget red and blue)."

One recent development the group will consider is the now widely accepted proposition that economically relevant information is typically scarce and local. Initially advanced by Friedrich Hayek in his critique of central planning, this idea has more recently been deployed to demonstrate that market failures — in markets for labor, credit, and information itself — are the rule, not the exception. The underlying problem applies with equal force to governments, whose capacities to address social problems are intrinsically limited by a lack of information sufficient to impose solutions by fiat.

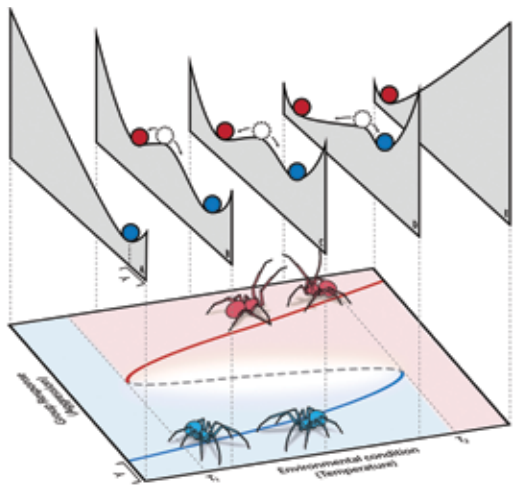
The second development — the behavioral revolution in economics — has led to a reconsideration of a fundamental tenet of the neo-liberal paradigm. This paradigm holds that citizens and government officials alike are amoral and self-interested. As a result, collective action by governments, trade unions or other bodies in civil society is seen not as a solution to social problems, but instead a pathology.

Carlin explains: "Because successful paradigms in political economy must provide guidance for public policy and broader societal governance — as did neo-liberalism and Keynesian social democracy — we will address policy challenges in the areas of economic insecurity, the predicament of high wage economies in a low wage global economy, modern monopoly, the organization of production, the urban-rural hiatus, intellectual property, and climate change."

Participants will include philosophers, economists, legal scholars, and political scientists, including SFI External Professors Luis Bettencourt (University of Chicago), a physicist, and economist Rajiv Sethi (Columbia University).

Wendy Carlin giving a presentation at the Bank of England in 2018. (Image: Stephen Swain)

RESEARCH NEWS BRIEFS



This image shows a hysteresis window between an environmental condition (heat) and group behavior (degree of infighting) in social spiders as they respond to heat stress. Groups that have been in an agitated state (red) tend to remain agitated, whereas calm groups (blue) tend to remain calm over a common temperature range. (Image: Mesa Schumacher.)

SOCIAL ANIMALS HAVE TIPPING POINTS, TOO

Many dynamic complex systems have tipping points where some small perturbation can cause an abrupt and dramatic shift — a bifurcation — in the behavior of the system. Once a system crosses a tipping point, it can have a difficult time returning to its previous state even if the environmental conditions are reversed. Scientists often need entirely different models to describe a system prior to and after it crosses a tipping point. In a September paper published in *Proceedings of the Royal Society B*, several SFI co-authors argue that social animal societies can also experience tipping points, and that further quantitative studies into these systems could lead to more effective conservation efforts.

EXHAUSTIVE ANALYSIS REVEALS CELL DIVISION'S INNER TIMING MECHANISMS

Understanding how and when cells divide is important to figuring out everything from how cancers grow to why some mammals are able to get so big. A new study of *E. coli* cell data, co-authored by Omidyar Fellow Jacopo Grilli and published November 7 in *Science Advances* suggests that simultaneous processes of DNA replication and septum formation triggers cell division. The new model could be useful for studying how non-bacterial life grows as well. This paper comes on the heels of a similar study in Cell Reports discrediting the often-accepted "bottleneck process" for cell division, pointing as well to concurrent cycles. "In biology or in other fields, we always think we need to get more data and more precise data to answer a question — that if we collect enough data, questions are going to answer themselves. But we also need good ways to look into the existing data," says Grilli.

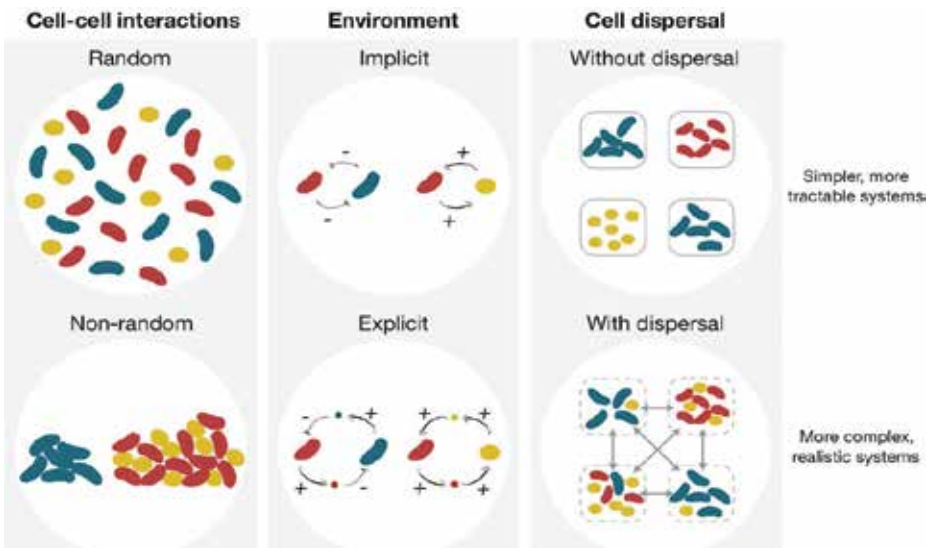
NEW DEFINITION RETURNS MEANING TO INFORMATION

A fish on the Great Barrier Reef continually acquires new information from its environment — the location of food, the murkiness of the water, and the sounds of distant ships, for instance. But only some of that information is meaningful and actually helps the fish survive. In various disciplines, from biology to artificial intelligence, identifying such meaningful, or "semantic," information is a key challenge. In an October paper in *The Royal Society Interface*, Postdoctoral Fellow Artemy Kolchinsky and Professor David Wolpert, propose for the first time a broadly applicable, fully formal definition of this kind of information. Semantic information, they write, is "the information that a physical system has about its environment that is causally necessary for the system to maintain its own existence over time."

> MORE ON PAGE 6

RESEARCH NEWS BRIEFS

(cont. from page 5)



The Variety of Potential Interactions between Organisms and Their Environment (Image: Sylvie Estrela).

THE COMPLEXITY OF THE COMMONS: SCIENTISTS RECAST SOCIAL DILEMMAS

Whether it's a pasture open to public grazing or a batch of glucose colonized by microbes, a shared environmental resource is often depicted as a fixed quantity, doomed to depletion if individuals selfishly consume what they can. This "tragedy of the commons" is a well-known scenario in a broader class of social dilemmas. But these paradigmatic dilemmas may be too simplistic, argue the authors, including External Professor Michael Hochberg and former Omidyar Fellows Eric Libby and Jeremy Van Cleve, in a November opinion piece in *Trends in Ecology and Evolution*. Two layers of complexity are often absent from classic social dilemmas: spatial and temporal. The next challenge, says lead author Sylvie Estrela, is "to understand when a simple model is good enough to predict the dynamics and evolution of social interactions…and where instead we need more complex and explicit models."

E. COLI'S ADAPTATION TO EXTREME TEMPERATURES HELPS EXPLAIN RESISTANCE TO CERTAIN DRUGS

Long before bacteria had to contend with antibiotic drugs, they had to survive extreme temperatures as Earth warmed and cooled over millennia. An August study published in *The ISME Journal* by a research team at the University of California-Los Angeles that includes SFI External Professors Pamela Yeh and Van Savage suggests that defenses against extreme temperatures give *E. coli* bacteria an advantage in fending off heat-mimicking drugs, also make them more sensitive to drugs that act like cold temperatures. Knowing this could help doctors administer antibiotics in a more precise way.

SOFT SKILLS NEEDED FOR THE DATA ECONOMY

As progress in science and technology advances at an increasingly rapid pace, universities must navigate how to train students in the skills they will need for future decades. Sometimes the courses offered in higher education misalign with industry needs or the latest research. A study published in *PNAS* by External Professor James Evans and co-authors offers visualizations and computational models to help decision-makers better understand the dynamic feedback between academic push and industry pull. Critically, the paper reveals that "soft skills" like communication and teamwork — the tools only humans can bring to increasingly data-driven jobs — are both underexamined in research and under-supplied through education.

HOW COMPLEXITY SCIENCE CAN QUICKLY DETECT CLIMATE RECORD ANOMALIES

The history of our climate is written in ice. Reading it is a matter of deciphering the complex signals pulled from tens of thousands of years of accumulated isotopes, but information in the ice can become corrupted, and scientists face a challenge of identifying the useful information. In a paper published in *Entropy*, SFI Omidyar Fellow Joshua Garland and External Professor Elizabeth Bradley show how tools from information theory can quickly home in on portions of data that require further investigation. The approach measures how much complexity appears at different time series in the ice. The spikes in complexity could mean points where major climate events, like a super volcano, introduced an anomaly, or an issue in the data processing pipeline.

UPCOMING COMMUNITY EVENTS

ANNOUNCING THE 33RD SEASON OF SFI COMMUNITY LECTURES THE LENSIC PERFORMING ARTS CENTER

For more than 30 years, our popular lecture series has engaged the Santa Fe community with lively and diverse talks exploring a variety of topics, from cutting-edge research insights to the nature of human creativity. Our 2019 series will include talks from the following confirmed speakers:

Danielle Bassett
Physicist, Systems Neuroscientist; University of Pennsylvania

Melanie Mitchell
Computer Science, Artificial Intelligence; Portland State University & SFI

Jean Carlson
Physics & Complex Systems; UC Santa Barbara & SFI

Olivia Judson
Evolutionary Biologist; Scientific Journalist

Laura Fortunato
Anthropology & Biology; University of Oxford & SFI

Srividya Iyer-Biswas
Physics & Biology; Purdue University & SFI

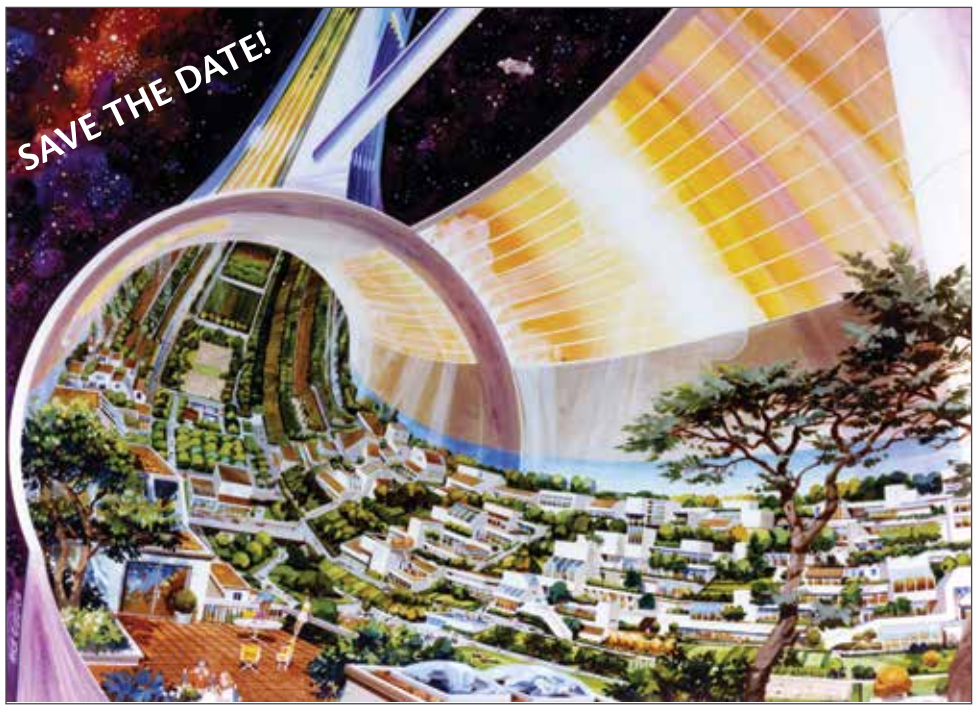
Lauren Ancel Meyers
Evolutionary Biology & Epidemiology; U TX Austin & SFI

Dana Randall
CS, Mathematics, Statistical Physics; Georgia Institute of Technology & SFI

Jessica Flack
C4 Collective Computation Group SFI

Up-to-date descriptions and event information information will appear on our website at santafe.edu/engage/community.

SFI Community Lectures are free and open to the public, thanks to generous underwriting from Thornburg Investment Management with additional support from the Enterprise Holdings Foundation. To stream these lectures live, subscribe to our youtube channel at youtube.com/user/santafeinst



The Stanford Torus Space Settlement design, considered in 1975 by the NASA Summer Study. (Illustration: Rick Guidice, courtesy NASA)

SANTA FE INSTITUTE'S 2019 INTERPLANETARY FESTIVAL FRIDAY–SUNDAY, JUNE 14-16 • THE SANTA FE RAILYARD, SANTA FE, NM

Santa Fe Institute's first Interplanetary Festival, held in June 2018, attracted thousands of Earth and space enthusiasts to downtown Santa Fe. The 2019 event is going to be bigger and better, with leading thinkers, creators, and scientists reimagining our future as a species. In between live concerts and panel discussions, participants may enjoy interactive expo booths, food, drink, and art installations that will refocus the imagination. The mission of SFI's InterPlanetary Festival: To change the world, one planet at a time.

Admission is free to all thanks to philanthropic support and sponsorships.

Check in at www.interplanetaryfest.org for the latest developments and to preregister.

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THE NEWSLETTER OF THE SANTA FE INSTITUTE
1399 Hyde Park Road
Santa Fe, New Mexico 87501
505.984.8800
www.santafe.edu