Spring 2018

Parallax

THE NEWSLETTER OF THE SANTA FE INSTITUTE

Ready for liftoff: SFI hosts first annual InterPlanetary Festival

SFI will be inaugurating a new annual tradition June 7–8 — the InterPlanetary Festival, which will render Santa Fe's Railyard district a platform for imagining future human civilizations, on and beyond Earth. The festival, running from noon to 10:30 p.m. both days, will include a series of discussions, interactive tech expo, film screenings, musical performances, and art installations, in addition to local beverages and food trucks.

Speakers at the festival will include Martine Rothblatt, founder of Sirius Satellite Radio and of biotech company United Therapeutics; Ashton Eaton, Olympic gold medalist and aspiring Mars colonist; Annalee Newitz, tech culture editor at Ars Technica; Seamus Blackley, a designer of Microsoft's Xbox; Cory Doctorow, editor of Boing Boing; and Nina Lanza, a geologist with the Space and Remote Sensing group at Los Alamos National Lab.

Talks and panels will focus on the complex life support systems essential to sustaining interplanetary civilization. These include: architecture, cities and scale; intelligent systems and cognitive assistance; social and economic engineering; time design; autonomous ecosystems; planetary regulation, rules, and law; astrobiology and life detection; motion and energy technology; and art and imagined futures.

In addition to these accessible science talks and panels, free festival events will include musical performances at an outdoor stage from Santa Fe funk band The Sticky, theremin virtuoso Rob Schwimmer, and Los Angeles-based multi-genre group Ozomatli. Movies like "Forbidden Planet" and "Star Trek II: The Wrath of Khan" will be screened at the Jean Cocteau Cinema. The Violet Crown, where space-themed beers will be on offer, will be screening "The Fifth Element," to be introduced by Scott Ross, who created the film's visual effects.

Above: *The InterPlanetary Festival logo was chosen from among 79 submissions from nine different countries. The designer, LeRoy Grafe, is an artist, photographer, and cinematographer currently attending the Institute of American Indian Arts in Santa Fe. (Image: LeRoy Grafe)*

Organizations interested in sponsoring the festival by participating in the InterPlanetary Innovations and Ideas Expo should contact the festival's director Caitlin McShea, at cmcshea@santafe.edu or 505-946-3651. Updates and further information on the InterPlanetary Festival are available at interplanetaryfest.org

Bill Miller funds SFI expansion

From its humble beginnings in 1983, with just a post office box and residential landline, SFI has grown into the physical space of its current home, the Cowan Campus. At the base of the Sangre de Cristo Mountains, this site provides offices and meeting space for some 30 residential faculty and post-docs, staff, scores of summer school students, and a regular stream of visiting scholars.

Sometimes, we're nearly bursting at our seams.

Supported by a $5 million donation from Bill Miller, Chairman Emeritus of the SFI Board of Trustees, SFI will begin realizing a longtime goal of expanding into a quiet property nearby in Tesuque.

The Tesuque property — a 36-acre estate with a constellation of buildings and trails 10 minutes from the Cowan Campus — was donated to SFI in 2012 by Eugene and Clare Thaw. In the years since, it has been an occasional retreat and meeting space.

"Scientific activity at SFI is ramping up," explains SFI President David Krakauer. "The Miller gift enables us to create the physical space we need to pursue our core research themes, while also providing a home for new outreach initiatives. It's a tremendous opportunity to extend the reach of complexity science."

While part of Bill Miller's gift will go to support the Institute's ongoing operations, the majority will fund renovations to the Tesuque property. These will include repairs and updates to the adobe buildings that dot the property and the establishment of hiking and meditation trails.

Once complete (anticipated in 2019), the renovated Miller Campus will house offices for the InterPlanetary Project, SFI Press, and Applied Complexity Network (ACtioN). It will also provide secluded workspaces for researchers and common areas for research retreats and small events.

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The water wheel of socio-hydro systems

Water is fundamental to all human activity. We need it to drink and irrigate crops, of course, and we use it to transport goods and generate electricity. There's a complex interplay between environmental conditions (a landscape's) and society (our policies, infrastructure, and individual behaviors).

"Water scarcity can change how people use water, which can trigger changes in collective behavior — government — which can then change the water system," says former SFI Omidyar Fellow Marion Dumas, now at the Grantham Research Institute at the London School of Economics.

Those feedback loops can lead to significant changes. For instance, a 2006 study of a water basin in southeastern Australia observed that early policies favoring agricultural use of water led to a cycle of resource degradation followed by policy responses that furthered that degradation. That left the system more vulnerable to crises.

But there isn't yet a robust framework for bridging the individual, institutional, and physical aspects of water systems research.

"Hydrologists and social scientists have independently addressed water-related research questions that are tractable without the other side," says Christa Brelsford, a former ASU-SFI fellow now at Oak Ridge National Laboratory. "But there is also true coupling where you can't understand the problem without understanding both sides."

For a workshop to be held June 11–14 at SFI, Brelsford and Dumas are convening scientists from fields ranging from hydrology and environmental engineering to political science and economics to find deeper ways of understanding and evaluating socio-hydrological feedbacks.

The meeting will allow space for participants to offer short presentations on their individual early stage work. But the heart of the meeting will be research jams — breakout sessions that mix researchers from different disciplines to share research methods, explore solutions to roadblocks, and begin to develop a common lexicon.

"People from different fields need sustained time to talk with one another, to learn each other's vocabulary and also what makes a good problem or a worthwhile question," says Brelsford. "And broadly, we want to identify what characteristics make a system more resilient."

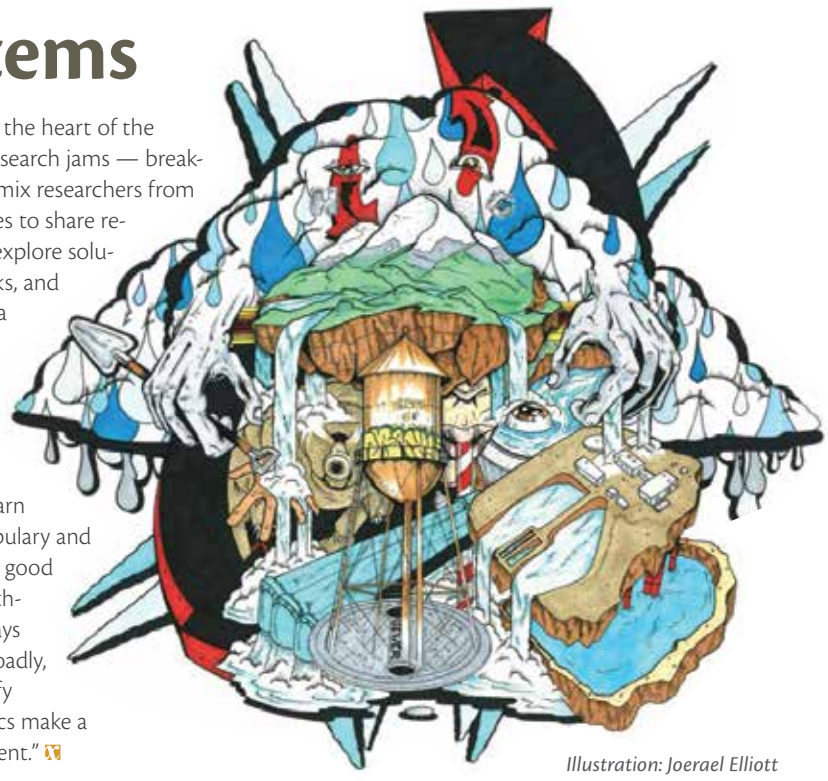

Illustration: Joerael Elliott

INSIDE . . . Incoming Postdoctoral Fellows . . . Parakeets to people . . . Social learning squared . . . MORE

BEYOND BORDERS

THIS JUNE the Santa Fe Institute is performing a large-scale cultural experiment. The hypothesis that is being tested is whether complexity science can change the way humanity thinks about the planet on which it was born. The question that the hypothesis seeks to answer is whether we can use SFI complexity science to train planetologists. The premise on which the question is based is that we need whole-Earth awareness.

At SFI we think that now is the time to ask and strive to answer this question. As populations grow and densify, as our dependence on technology increases, as resources are diminished, as our human global footprint swells into a deadly boot, as societies polarize, and our connections grow, all the while developing the technologies to scan and explore the far reaches of space, we need new paradigms that respect our diverse and hybrid nature. We are no longer villages or nations of people but networks of variegated cultures and values symbiotic with machines.

SFI's contribution to this debate is the InterPlanetary Project. Whereas the mission of SFI is "Searching for order in the complexity of evolving worlds," the mission of the InterPlanetary project is "Changing the world one planet at a time." SFI and InterPlanetary are the yin and yang of complexity, one foundational and one aspirational, the first basic and the second applied.

In pursuing this project we are cleaving to one of the deepest insights of science fiction, as articulated by the Polish writer Stanislaw Lem:

"Man has gone out to explore other worlds and other civilizations without having explored his own labyrinth of dark passages and secret chambers, and without finding what lies behind doorways that he himself has sealed."

The InterPlanetary Project is no plan B, no irresponsible effort at escape; it is the expression of our belief that in order to engage with the most pressing problems of today, we need to imagine the challenges of tomorrow. Inspired by Mark Twain when he wrote, "You can't depend on your eyes when your imagination is out of focus," InterPlanetary seeks to restore focus at a planetary scale.

We are asking the whole world to join us on this expedition. It needs to be fun, it needs to be deep, it needs to respect complexity and diversity, and it needs to make a difference.

If you join us we will make a difference.

— David Krakauer
President, Santa Fe Institute

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SFI IN THE NEWS

Slate, on March 13, dug into some of the economic commentaries at the heart of modern science fiction, including stories by **Ken Liu**, who has built his imagined worlds, in part, around External Professor **Brian Arthur's** (Palo Alto Research Center) texts.

On March 7, *Scientific American* highlighted External Professor **Jon Machta's** (University of Massachusetts, Amherst) use of an equation for magnetic behavior to describe the fruiting patterns of pistachio trees.

A new statistical concept could explain why, after exposure to a virus, some people get sick sooner than others, wrote *Quanta* on March 1, highlighting work by former Omidyar Fellows **Ben Althouse** (Institute for Disease Modeling), **Sam Scarpino** (Northeastern University), and External Professor **Aaron Clauset** (CU Boulder).

External Professor **Aaron Clauset** (CU Boulder). talked with *Nautilus* and *Newsweek* about his analysis of "the long peace" since World War II and what statistics do and don't reveal about the likelihood of a future major war. The articles were published on March 1.

Ars Technica explained on March 1 why questions about peoples' friends can help predict elections, based on new research by Professor **Mirta Galesic**, former Omidyar Fellow **Marion Dumas** (London School of Economics), and colleagues. The research was also featured in the podcast Dastardly Cleverness in the Service of Good.

Scientific American cited **Michael Mauboussin**, Chairman of SFI's Board of Trustees, in a March 1 blog about the relative roles of skill and luck in shaping life success. Mauboussin was also quoted in a Feb. 12 *Forbes* article about AI and the future of investment management.

A Feb. 5 *New York Times* article on animal numerosity cited External Professor **Mark Pagel's** (Reading University) recent study of low-limit number words across human languages

Vice Media's *Motherboard*, on Feb. 16, featured a new extinction model by SFI External Professor **Justin Yeakel** (UC Merced), and SFI Professors **Chris Kempes** and **Sid Redner**. Their model, which incorporates body size and reproduction, predicts the "ideal" mammal, Cope's Rule, and Damuth's Law.

Quanta, on Feb. 15, featured a new study by External Professor **Aaron Clauset** (CU Boulder) and co-author **Anna Broido** (CU Boulder), which questions "the tacit and common assumption that all networks are scale-free and it's up to us to figure out how to see them that way."

In a Feb. 13 podcast, *The Investor Field Guide* interviewed SFI Trustee **Josh Wolfe** about his complexity-inspired approach to venture capital.

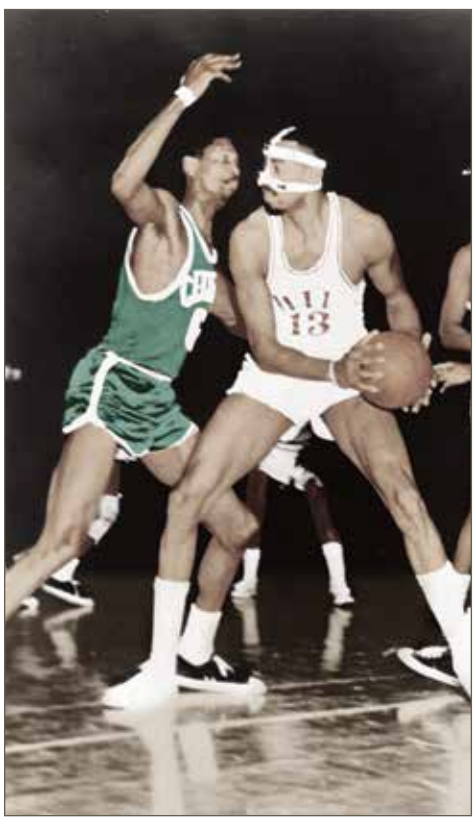
Building on External Professor **John Geanakoplos'** (Yale University) ratio for Middle-aged to Young investors, a Feb. 4 *Wall Street Journal* article surmised stocks could rise through 2035.

Urban experts, including SFI's **Geoffrey West**, co-signed an appeal to leaders at Amazon HQ2 finalist cities, asking for a mutual non-aggression pact. The document was published Jan 30 in *Wired*.

Conventional wisdom holds that conflict is negative, but new research by **Eleanor Brush** (University of Maryland) and SFI's Collective Computation Group (C4) suggests controlled conflict can improve decisions and create a better social structure. SFI Professor **Jessica Flack** described how this works in an interview that aired Jan. 20 on the Canadian Broadcasting Corporation's "Quirks & Quarks" program.

In an article about America's growing guard labor workforce, *The Atlantic*'s CityLab cites research by SFI Professor **Sam Bowles** and **Arjun Jayadev** (University of Massachusetts Boston).

Citing Professor **David Wolpert's** famed *No Free Lunch* theorems, the February issue of *Harper's* characterized the future as "a collection of specialized AIs: the lesser gods of loan assessment and weather prediction."



Bill Russell and Wilt Chamberlain go toe to toe during a basketball game. (Image: New York World-Telegram and the Sun, via Wikimedia commons)

Workshop to explore team culture and human performance

On March 2, 1962, Wilt Chamberlain scored an astounding 100 points in a game against the New York Knicks — a record that still stands. There's no doubt that Chamberlain is a giant among basketball players. But no player operates in a vacuum. How much did team culture or the collective mood on the court contribute to Chamberlain's exceptional performance that day?

This question of how the collective influences individual performance is central to the work of SFI's investigation into the limits of human performance. In a workshop to be held July 9–11, experts from a range of disciplines, including physiology, organizational behavior, sports analytics and applied mathematics, will explore how the collective affects the individual — including on the basketball court.

"There's been a lot of work on time series to see what the chance is of making so many baskets in a row. But what is the likelihood of a streak based on what the team is doing as whole?" asks SFI Professor Jessica Flack, the director of SFI's Collective Computation Group and organizer of the July 2018 workshop.

The workshop — the group's second on the subject of human performance — will identify key questions to explore further at a larger workshop in 2019. While the focus will be on sports, the insights these sessions will yield can apply to other fields as well, such as biology and economics, Flack says.

"Sports naturally lend themselves to this issue, because of team chemistry, team culture, and how it relates to individual performance on the field," she says. And because games are videotaped, a lot of data can be gleaned from analyzing those videos.

But even in individual sports such as marathon running, the collective comes into play, she adds. "There are collective effects, like pacing, and runners running in clusters," she says. "And that seems to affect their times. So understanding why that synchronicity happens would be fantastic." The military, too could benefit from understanding these relationships between the collective and the individual, she adds.

Loosing the arrow of complex time

In 1928, Arthur Eddington introduced the world to the arrow of time — the idea that time is unidirectional. Time flies forward, like an arrow, and as a result we cannot reverse most physical and biological processes. We cannot return to the origins of the universe, age backwards, or take the cream out of our morning coffee. The arrow of time is borne of the second law of thermodynamics which tells us that closed systems tend toward increasing entropy. We can't go backwards because, in closed systems, entropy is ever-increasing.

Fast-forward to the present day. With support from the James S. McDonnell Foundation, SFI has launched a new, major research theme—Aging, Adaptation, and the Arrow of Time—to ask whether a theory of complex time can help us explain aging across physical and biological systems. This spring, SFI is devoting its 2018 Science Board Symposium to the theme and will also host a June workshop on "The Origin and Implications of Time in Adaptive Systems."

"We want to know how time connects what happens in physical systems with social systems, and biological systems, and how those systems are related," says cosmologist Sean Carroll at the California Institute of Technology, who is participating in both the symposium and the workshop.

Complex time is the idea that time moves forward at different scales for different systems. Larger animals tend to live longer than smaller ones, and they age in proportion to their body mass. Companies tend to have shorter lifespans than colleges or constitutions. How are we to understand these different lifespans, and their relations to one another, across systems?

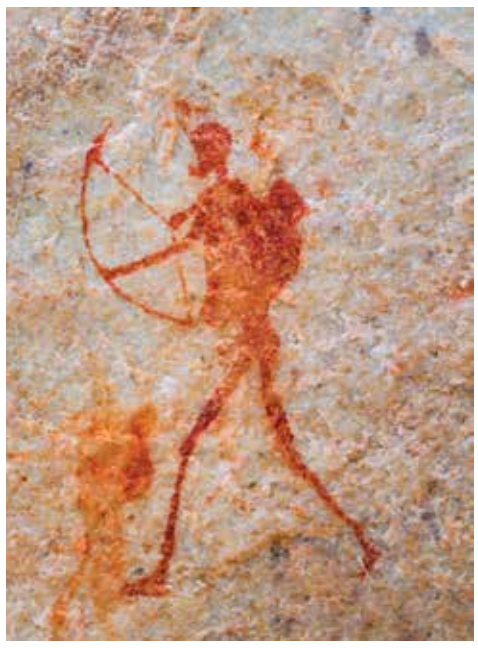
Complexity scientists often understand time in terms of information gains and information losses: adaptation is a kind of information gain; decay is a kind of information loss and entails an increase in entropy. For Carroll, the kind of complex phenomena that interest SFI researchers lie between low entropy and high entropy states. We might be inclined to think that low entropy gives us complex order. But as Carroll explains, "for complex systems to arise, it's necessary that entropy increases over time."

Understanding the transition from the low entropy beginnings of our universe to the emergence of complex systems lies at the heart of complex time research.

The symposium, to be held May 4–5, will kick off an ongoing series of time-themed science events, followed closely by the workshop June 18–20.

Geophysicist Amy P. Chen, who manages the program, says its ultimate goal is not only to understand time, but find ways to mitigate loss — like the loss of neurological function that comes with aging.

Mercedes Pascual, who co-chairs the Science Board at SFI, hopes that the theme "will help us better understand how aging is related to the underlying and evolving structures of complex systems."



The Archer, Sevilla Bushman Rock Art Trail (Image: Alamy Stock Photo)

ACHIEVEMENTS

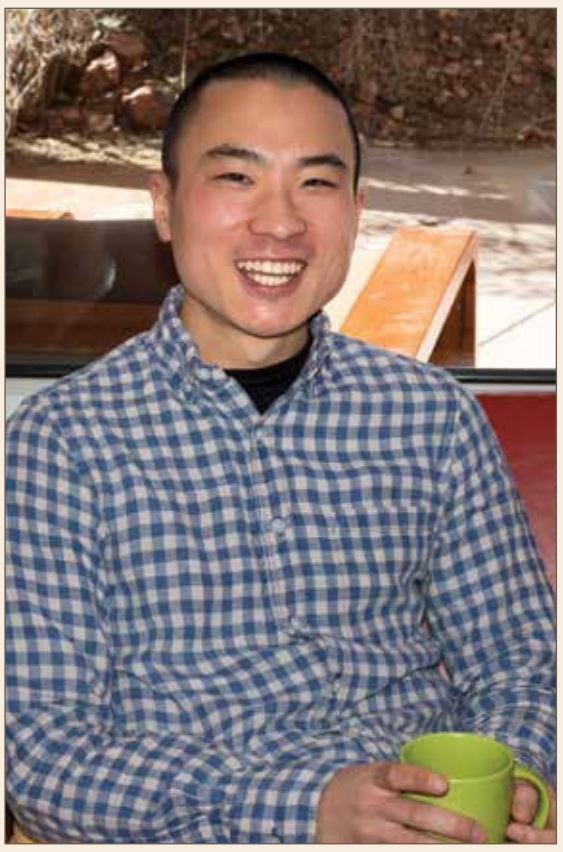
The Coalition for Archaeological Synthesis (CfAS) has awarded $50,000 to archaeologist **Stefani Crabtree** (Penn State), SFI VP for Science **Jennifer Dunne**, and their collaborators. The grant supports "The ArchaeoEcology Project" — an investigation into how humans, across millennia, have interacted with the species and ecosystems around them. To understand how humans shape ecological networks, the project combines "the deep-time perspective of archaeology with data from the allied disciplines of ethnography, ecology, climate science, and geology," according to the CfAS announcement.

External Professor **Pablo Marquet** (Pontificia Universidad Catolica de Chile) has been elected a Fellow to The World Academy of Sciences, which advances science in developing countries. Membership in TWAS as a fellow recognizes recipients' significant contributions to science. Marquet, an ecologist, has worked on scaling and power laws to better understand patterns in ecological systems, the sustainability of human activity on Earth, and the biological basis of human social and cultural complexity.

Incoming Postdoctoral Fellows

ALBERT KAO

The emergence of collective intelligence



It's hard enough to figure out what makes an individual ant, bird, or human intelligent, but harder still to identify what makes a group intelligent. Incoming Omidyar Postdoctoral Fellow Albert Kao is looking into to decentralized systems, asking questions like: what principles might make one flock of birds more successful than another, and how might we use those principles to nudge a group towards better performance?

Kao, who has a Ph.D. in ecology and evolution from Princeton University, has studied slime molds to understand how they transmit information in a decentralized manner. He's also interested in theoretical applications of his work to areas as widespread as plant root systems and social media.

"I've always been interested in neuroscience," he says, "but neurons are contained in the body. Animal groups exist across space. Each animal is sensing something different, making an animal group a sensory, computational, decision, and movement array all at once."

His work pushes the boundaries of biology by connecting insights from species as different as slime molds, birds, and humans, and he plans to continue in this vein during his time at SFI. "Think of is as a wisdom of crowds," he says, "but for all species."

Kao comes to SFI from Harvard University and will arrive in August 2018.

ASHLEY TEUFEL

The evolution of diversity

Despite the biological diversity we can see during a simple stroll in the park, for the first three billion years of life on Earth, things weren't all that diverse. It was only about half a billion years ago that *something* happened — though scientists still lack a satisfying explanation for why biodiversity exists.

Ashley Teufel, an incoming Omidyar Postdoctoral Fellow who is joining SFI from the University of Texas at Austin, has a hunch about what that *something* might be. Building on the second law of thermodynamics — the idea that entropy, or disorder, cannot decrease over time — Teufel theorizes that, once at a certain level of complexity is attained, irreversible changes will spur on further changes. Biologists call this entrenchment.

"I think of myself as a computational, molecular, evolutionary biologist," says Teufel, who completed her postdoctoral work in molecular biology at the University of Wyoming. "That means I make mathematical models on computers of evolution." So far, Teufel's work has focused on evolution at the metabolic level — proteins, metabolic pathways, and gene duplicates . While at SFI, she plans to extend her research to other complex systems.

"A very long time ago I used to be an ecologist," she explains. "If my findings apply in molecular biology, why wouldn't they apply to other complex systems? I'd love to get back to my roots as an ecologist."

Teufel will arrive in the fall of 2018.

HAJIME SHIMAO

Bridging theory and data

Many economic models start with an assumption about how individuals should behave, then scale up from there. A rational consumer should buy the new smartphone if it meets her need for a portable camera; a college graduate should choose an occupation that matches her skills.

For Hajime Shimao, research in economics should start with a fundamental question: what's the best model for the empirical data?

Shimao has spent the past six years at Purdue University earning his Ph.D. in economics. His dissertation explores how theoretical models of economic phenomena map to real-world observations — a branch of economics known as econometrics. Before he began his graduate studies at Purdue, Shimao had earned a master's degree in decision science at the Tokyo Institute of Technology and a bachelor's degree in psychology from the University of Tokyo.

At SFI, Shimao will be working with Professor David Wolpert to understand why human social organizations have the structures they do — a longstanding question in the social sciences. Shimao and Wolpert are taking a macroscopic approach, treating individuals as nodes in a vast organizational network. They'll study how information flows through different network structures, with an eye toward creating a theoretical model that can explain a variety of human social organizations, from chiefdoms to modern tech firms.

"The simpler the model, the more it can explain," Shimao says. "I can be a bridge between the model and the empirical data."

Shimao will join SFI in June 2018.

VICKY CHUQIAO YANG

Scaling, human irrationality, and the future of democracy

Incoming Omidyar Fellow Vicky Chuqiao Yang is driven by two difficult and seemingly unrelated questions: How do social systems change across scales; and how do we make sense of human irrationality in mathematical models? Yang, trained as an applied mathematician with a Ph.D. from Northwestern University, will arrive at SFI in September 2018.

When a city grows, different social phenomena change at different rates. For instance, Yang has used FBI crime reports to show that the number of robberies per capita, like the number of patents, increase faster than the rate of population growth, while the incidence of rape per capita increased proportionally. Where previous scholars have found this to be a shortcoming of scaling laws, Yang thinks it's a feature begging for further study.

As to Yang's second question: Much research on human decision-making assumes that humans are rational and will act in their own best interest. But experimental and empirical research suggests that humans simply don't behave that way a lot of the time.

Yang is looking for ways to incorporate this empirical reality into theoretical models, applying the idea of *satisficing* — finding an outcome that is "good enough" rather than the best — to voter models.

Yang plans to combine her two interests to better understand how democracy works at different sizes. If we know that properties of cities are different as they increase, and we know that humans have some predictably irrational tendencies, Yang wants to know: what happens when countries with democratic governments increase in size?

Incoming Omidyar Fellow Maria Riolo will be profiled in the next issue.

An introduction to SFI's visiting faculty

Three researchers are spending several months at SFI, using their time here to tackle some big questions: "Why do we sleep less as we get older?" "What do city pigeons have in common with drug interactions?" and "Is there a trajectory underlying human history?" to name a few.

Pamela Yeh is commuting to and from UCLA where she runs the Yeh Lab in the Department of Ecology and Evolutionary Biology. A field biologist by training, Yeh studied the evolution of city-dwelling birds before moving to bacteria and drugs in the lab.

"Think about a bird in an urban environment," she points out. "Suddenly it has to deal with noise, with artificial light, with buildings, human disturbances. But how do those selection pressures interact?" These stressors can interact synergistically, antagonistically, additively — with striking similarities to the ways that drug interactions in the body can be understood.

"It turns out that question is almost universally asked in every single field," says Yeh. Economists, for example, "might not call them stressors, but they have a different word for it: positive or negative factors." Political scientists follow the same reasoning, asking what information sources interact to build political beliefs.

Joining Yeh is External Professor Van Savage, also from UCLA where he is a professor in the Department of Ecology and Evolutionary Biology and the Department of Biomathematics. He was originally introduced to SFI as a graduate student almost twenty years ago, and returned for three years as a postdoc before becoming an SFI External Professor.

He's currently collaborating with SFI Distinguished Professor and Past President Geoffrey West to investigate the origins of sleep and its changes over an animal's lifespan, an inquiry he originally began while a postdoc here years ago.

"I'm very eclectic in the way that I think about science," he confesses. He jokes that his Ph.D. in theoretical high-energy physics was in "measuring the weight of the God particle" — a far cry from food webs, another of his current research interests.

The beauty of SFI, he notes, is in its collaborative opportunities, both intentional and surprising. In addition to his work with West, he'll be digging deeper into the interplay between complexity and stability in large networks such as food webs and vascular systems. "When I came here, I thought, Jen Dunne [SFI Professor and Vice President for Science] is the perfect person to talk to about that," he says. "What I didn't realize before I came here, is that Jacopo [Grilli, Omidyar Postdoctoral Fellow] is completely immersed in all that literature. So coming here is even better than I thought!"

Both Yeh and Savage arrived in January and depart at the end of March.

Also visiting is External Professor Laura Fortunato (University of Oxford), an associate professor in evolutionary anthropology and former SFI Omidyar Fellow. Like Yeh and Savage, she stresses the importance of looking at many factors simultaneously.

"Some people say you can break things apart, but anthropologists would say you can't look at [a system] separated out," she says. "Cultural features have to be viewed as an ensemble, where one thing affects others."

After a first degree in biology, Fortunato pursued a Ph.D. in anthropology. As she puts it, "I made humans my species of choice." Her initial research focused on kinship and marriage systems, moving toward cultural evolution and redefining "social complexity" in quantitative terms. "We all have a hunch about what it means," she says, "but to go *measure* it is a different thing."

Left to right: Laura Fortunato, Pamela Yeh, and Van Savage. (Photo: Kate Russell for the Santa Fe Institute)

A new direction she is exploring during this visit is a project that uses of economic "games" to study behavior and network dynamics in human groups. She hopes that her work, with its computational approach, can contribute to redirecting the field toward more nuanced approaches to the study of human behavior.

Fortunato arrived in October, 2017 and departs at the end of March.

All three visitors highlight SFI's unusual and inspiring approach: an explicit celebration of cross-disciplinary work that's sometimes difficult to find in other institutions.

"There's so much lip service paid to interdisciplinary work, and multi-disciplinary work, trans-disciplinary work — but it takes a real commitment to keep trying to figure out your common ground," says Yeh. The project she and Savage are working on with Mirta Galesic, for example, has already been through several years of discussion. But its goal — to approach organism and social stressors from the perspectives of biology, network theory, and social science — would be unreachable without the time they've put into forming a common language.

"When you're at this interface, maybe you're not as bound by all these traditional ideas," says Yeh. "You can make progress by leaps and bounds, rather than by these tiny increments."

"There's a difference between just 'gluing' things together and making them really integrated," agrees Savage. The latter, he notes, is what SFI is trying to do — and why it's such a pleasure to be here.

Did animals rise with oxygen?

In late April, SFI will host a three-day working group to explore the effect of increasing oxygen on the early evolution of animals.

"For decades, there have been outstanding questions about the issue of oxygen and early animal evolution," says organizer Doug Erwin, SFI External Professor and Senior Scientist at the Smithsonian's National Museum of Natural History.

The origin of animals at least 600 million years ago was a critical event in Earth's history. Their millions of descendants include jellies, trilobites, worms of every description, octopuses, and vertebrates like us.

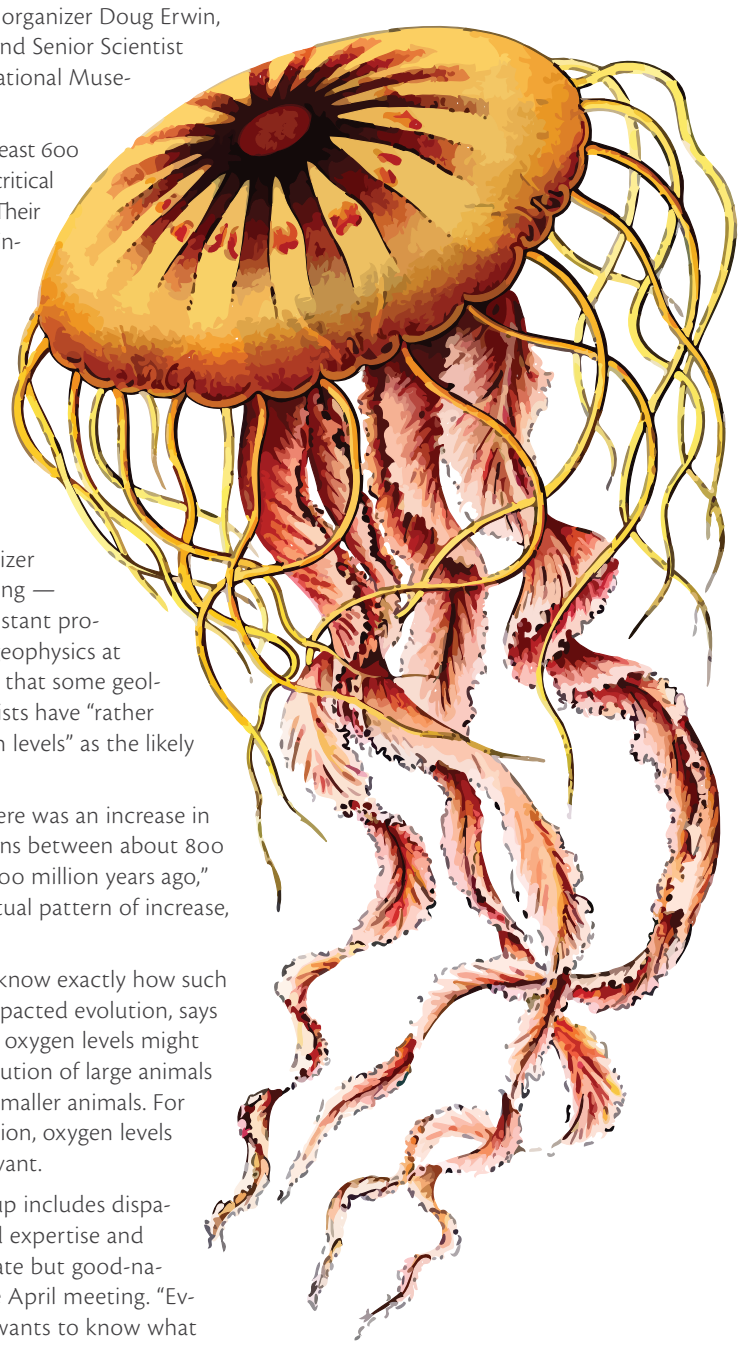
What triggered the appearance and diversification of the first animals is a subject of intense interest. Erwin and his co-organizer of the upcoming meeting — Noah Planavsky, an assistant professor of geology and geophysics at Yale University — note that some geologists and paleontologists have "rather blithely invoked oxygen levels" as the likely trigger.

"It's pretty clear that there was an increase in oxygen in shallow oceans between about 800 million years ago and 500 million years ago," says Erwin. "But the actual pattern of increase, we don't know."

Researchers also don't know exactly how such changes might have impacted evolution, says Erwin. A sharp jump in oxygen levels might have triggered the evolution of large animals capable of preying on smaller animals. For other aspects of evolution, oxygen levels might have been irrelevant.

The small working group includes disparate points of view and expertise and Erwin expects passionate but good-natured discussion at the April meeting. "Everybody in the group wants to know what the answers are. If we have some consensus on some of these issues, it will make it more obvious how to move forward."

At the end, the group will summarize their conclusions, outstanding questions, and new directions for research in a paper for the journal *Geobiology*.



Jellyfish, extracted from a print from "Kunstformen der Natur" by Ernst Haeckel, 1904 (Image: Public domain)

Decisions, decisions: Working group explores two-step process for collective computation

In May, complexity scientists will be meeting at SFI to examine how collective decisions get made in biological systems and to what degree those systems share a mechanism from one system to the next.

"From neurons making decisions in the brain to fish deciding which way to swim, to cell differentiation — you have one type of stem cell that eventually makes a choice to be a heart cell or a liver cell — they share some of the same properties, we think," says Bryan Daniels, an ASU-SFI researcher and one of the organizers of the working group. "We have a few overarching ideas, conceptual frameworks, and the goal is to see to what extent they actually match to this diversity of systems."

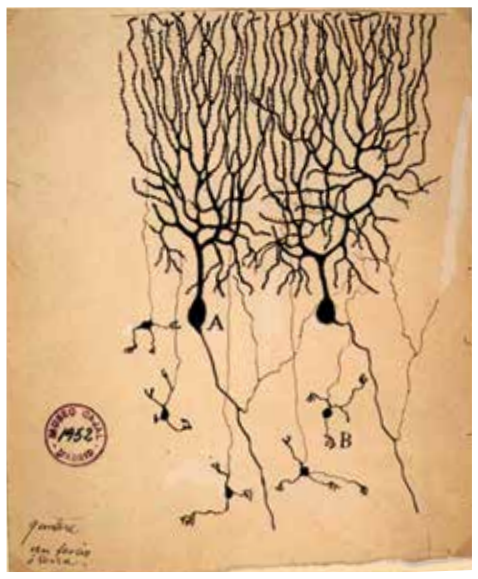
One commonality observed in diverse systems with multiple decision-making actors involved has been a two-step overall decision-making process that consists of information accumulation followed by a period of aggregation, where that information is turned into actions.

SFI's Collective Computation group (C4) observed this in data drawn from neurons involved in a perceptual decision task. At one point, the upcoming decision was coded in a distributed way among many of the neurons, but this rapidly changed. According to Daniels, all of the neurons came to consensus "just before the actual output."

A similar process has been observed in ants choosing a nest. Early on, scouts would go to a variety of nests seeking an optimal colony site, but at a certain threshold, their actions shifted: Ants would move to just one nest, with some even picking up others to take them there.

Eventually the hope is this type of research will yield insights into the decision-making behavior of groups of humans. Whether observing the process in a variety of biological systems can shed light on ways to optimize the process or outcomes — for example, by altering how much time to give to either the information accumulation or the ultimate decision making phases.

"The first thing we wanted to do is ask: how is it done in biology?" Daniels says, "the obvious extension is to ask if this is a better way of doing this computation."



Drawing of Purkinje cells (A) and granule cells (B) from pigeon cerebellum by Santiago Ramón y Cajal, 1899.

SFI expansion *(cont. from page 1)*

Tom Easterson-Bond, the architect heading up the renovation, is planning to preserve the contemplative atmosphere of the property while adding more space for collaboration.

"The Santa Fe Institute is metaphorically a Monastery in the Mountains — living at the edge of wilderness and society," Krakauer says. "The Cowan Campus offers a quiet space for contemplation and conversation — a headquarters for basic complexity research. But after thirty years, we're ready to expand and to bring the ideas from the 'Monastery' back to the 'Metropolis.' The Miller Campus — SFI's second 'Monastery' — will help support the introduction and application of complexity science's big ideas and insights into the world."

Q&A: From parakeets to people — with Elizabeth Hobson

Elizabeth Hobson (Photo: Kate Russell for the Santa Fe Institute)

SFI External Professor Simon DeDeo (Carnegie Mellon University), ASU-SFI Fellow Elizabeth Hobson, and Dan Mønster (Aarhus University) recently received a grant from the Army Research Office to conduct social science research. Their project will look at how humans understand social interactions and form ideas about social structure.

Science writer Katherine Mast chatted with Hobson about the upcoming experiments and how this research into human behavior draws on her previous studies on the social lives of parakeets.

Tell us about the experiments you have planned through this grant.

We're going to have undergrads play a networked computer game. They'll compete for rank in a dominance hierarchy, and we won't allow any kind of communication. Then we're going to pay them for participating based on how high in rank they get.

Behind the scenes, we're going to dial up the amount and the type of social information we give them — like how many past events to show them on the screen and more global emergent knowledge about which individuals are top ranked vs. bottom ranked — and see how that changes strategies and ability to gain rank in the hierarchy.

What are the backgrounds of this trio of researchers?

We're an ex-cosmologist-turned-social scientist — that's Simon, who is the lead investigator — and me, mostly coming from biology and behavioral ecology, and Dan, who's an ex-physicist-turned-behavioral economist.

Most of your previous work has been with animals. What's different about doing a human study?

Right now, I'm working with a big historical data set of how animals fight that goes back to 1934. The way that individuals are choosing to fight gives you a lot of insight into what they're paying attention to and what kinds of information they are using to make their decisions.

There's a lot of processing that goes on in the human mind that is probably very different from animal minds — complicated strategizing, trying to figure out what the experimenters want and trying to act on those expectations.

What results do you anticipate?

One of the strategies might be very basic: if you attack me in the game and I retaliate and attack you, we get stuck in an endless loop of retaliating against each other. That's not going to help either of our ranks. Tying the individuals' ranks to their payment could be a cue to break these unproductive strategies.

We might also see collusion or cooperation — attacking a common enemy — but in the total absence of any kind of communication.

What's the connection to your prior work with parakeets?

A lot of the math that underlies these networked computer games is the same that Simon and I developed to work with parakeet data. With the parakeets, I observed them for about a month at a time. We're not going to trap the undergrads for a month — we're going to do it over a couple of hours. It will be interesting to see if similar types of strategies and social structures emerge to what we saw in the parakeets or if things are totally different when you start looking at humans and compressing the timescales.

In previous work, Hobson and DeDeo linked the ability to determine rank amongst monk parakeets to an act of cognitive reasoning. (Photo: Greg Matthews)

As humans, we have arguably the most complex social structures of any species. It's been a big mystery how we got to that level of social complexity. Previous research has focused on the connection between social and cognitive complexity. But we don't know how hard it is to process social information. That's one of the things that we hope to get at with this project: just how hard is it, and what happens as we tweak the amount and type of information that we're allowing people to use.

Social learning squared

For decades, a wide variety of research communities have each been studying how individuals learn from one another, and how that shapes the broader network. But these communities rarely share their findings across academic boundaries.

"Each field is more or less independent, but the conclusions they've found are somewhat similar," says SFI Professor Mirta Galesic, who is organizing a workshop that will meet April 16-19. The meeting will convene a range of researchers from psychologists and evolutionary anthropologists to statistical physicists and computer scientists to share (socially) what they have discovered independently about social learning.

Computer scientists might glean tools from animal and human researchers that could help them design better machine learning algorithms. Statistical physicists might offer insights about why certain rules work, while psychology could advance the insights about what people do toward what is good for us to do.

Computer scientists have already learned from biology how social insects like ants and bees work together to solve problems. For instance, ant colony optimizations algorithms, developed from an understanding of how ants use pheromone trails to find food, have been used to model protein folding and to optimize traffic routing.

"We've learned how ants and bees explore a space for possible solutions and then communicate to each other what they've discovered," says Galesic. "Maybe this workshop will allow us to add how humans do it."

Psychologists, like Galesic, have a lot of qualitative insights into how people learn. But they don't have good quantitative models to transfer that knowledge into social networks to understand how beliefs spread. Insights from computer science could also help psychologists study what conditions make it more effective to learn on your own, and when it's better to learn from others.

The more people from different fields talk to one another, the more they are discovering they have come across similar findings independently. "One discipline may have findings that resemble what another discipline has already been doing for 20 years," says Galesic. That can give the false impression that people have been doing interdisciplinary work. "It's really just that they are rediscovering the same outcomes."

By providing a space for true interdisciplinary conversations, Galesic hopes the group can begin to understand how broad these common findings really are.

Computer scientists have already learned from biology how social insects like ants and bees work together to solve problems. (Image: iStockphoto.com)

RESEARCH NEWS BRIEFS

A pistachio orchard near Kettlemen City, CA. (Image: Curran Hughes)

HOW PISTACHIO TREES ARE LIKE MAGNETS

Using data from over 6,500 trees in a pistachio orchard across five years, External Professor Jonathan Machta (UMass Amherst) and colleagues find fractal-like spatial patterns of fruit production similar to the emergent behavior of magnets near a critical point. Their finding suggests that one tree may "tell" another when it's time to blossom, influencing patterns of yield. The study was published in February in *Proceedings of the National Academy of Sciences*.

THERE'S NOTHING UNUSUAL ABOUT "THE LONG PEACE"

During "the long peace" of the 1945–2003 post-war period, only five interstate wars occurred. In the century before, between 1823 and 1939, major conflicts occurred every 6.2 years, with a particularly violent period between 1914 and 1939 where they occurred every 2.7. Using data on interstate conflicts worldwide between 1823 and 2003, SFI External Professor Aaron Clauset (CU Boulder), created models to determine the plausibility of a trend toward peace since 1945. His results, published in February in *Science Advances*, indicate that the long peace pattern would need an additional 100–140 years to become a statistically significant trend. The long peace simply balanced the books against earlier violent years.

WORDS FOR "LOW-LIMIT" NUMBERS PERSIST FOR CENTURIES

In a study published in January in *Philosophical Transactions of the Royal Society B*, External Professor Mark Pagel (University of Reading) and colleagues have discovered that "low-limit" numbers — particularly two, three, and five — are consistently among the oldest words in the Indo-European language family. This trend continues in languages of Africa and the Austronesian languages of the South Pacific. In all these language groups, short words are replaced at an exceptionally low rate — an average of ~13,000 years. That is perhaps due to the brain's ability to perceive small numbers of objects without counting. Researchers cite evidence that animals can perceive numbers even though they lack any formal counting system.

THE RIGHT TOOL FOR THE JOB

Although complexity is hard to define, it easy to identify and handle if the appropriate tool is applied, say External Professor Constantino Tsallis (Centro Brasileiro de Pesquisas Físicas) and colleague Debarshee Bagchi. In a paper published in February in *Physica A*, they demonstrate which statistical methodologies are best applied to which types of complex systems. For instance, standard Boltzmann-Gibbs statistics is adequately applicable to short-range interactions like a system of air molecules, while Tsallis' own q-statistics give better results for long-range interactions such as a galaxy and its stars. The authors adjust a term in the Fermi-Pasta-Ulam-Tsingou problem to show how q-statistics give way to Boltzmann-Gibbs when the correlations strongly decay in space and time, in contrast with, say, gravity, which exerts a strong pull on distant elements in the system.

> MORE ON PAGE 6

New online class offers tools for tackling fundamental questions

For more than a century, scientists have been using probability and statistics to measure the natural world. They want to make sense of data and find meaningful signals in the noise. But in the last few years, classical statistics have started to seem a little threadbare. Researchers now have access to large datasets, which are driving new insights in disciplines ranging from biology to ecology to economics. It's as true in biology, with the advent of genome sequencing, as it is in astronomy, with telescope surveys charting the entire sky.

Multi-colored powder explosion by Pattadis Walarput (Image: iStockphoto)

The data have changed. Maybe it's time our data analysis tools did, too.

That's one of the core ideas behind Algorithmic Information Dynamics, a new online course offered through Complexity Explorer, SFI's online education portal.

The class will help students use concepts from the field of algorithmic complexity to search for solutions to fundamental questions. Scientists have long observed connections in natural systems, but finding evidence of causality — that is, why this set of circumstances leads to that outcome — is a thorny problem outside the scope of classical statistics. The class will introduce algorithms that can be used as tools that move beyond traditional mathematical approaches and harness the ideas of complexity to better illuminate causality.

Hector Zenil and Narsis Kiani, who lead the Algorithmic Dynamics Laboratory at the Karolinska Institute in Stockholm, Sweden, teach the course. The first part will introduce and explain the preliminary concepts needed to understand the second part, which is research-driven. Participants will analyze their own data through the new algorithmic tools.

"Our idea is to ask students to perform experiments on their own data," says Zenil.

The approach introduced in the class can be applied to any discipline, says Zenil, from biological evolution to finance to physics to psychology. And while they may not provide answers to every question about fundamental causes in nature — "in the natural world, there are open questions that cannot ever be solved," notes Zenil — these tools give researchers sophisticated ways to deal with big data.

Algorithmic Information Dynamics opens in June. The cost is $50 and includes a textbook; financial aid is available.

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RESEARCH NEWS BRIEFS

(cont. from page 5)

TO PREVENT COLLAPSE OF TROPICAL FORESTS, PROTECT THEIR SHAPE

An interdisciplinary team of scientists led by Laurent Hébert-Dufresne (University of Vermont), a former postdoctoral fellow at SFI, has made a fundamental discovery about how fires on the edges of tropical forests control their shape and stability. Using high-resolution satellite data from protected forests in the savanna region of the Brazilian Cerrado, the scientists find that the shape of these natural forests follows a predictable mathematical relationship between a forest's perimeter and its area — regardless of its climate region or its size. Their study, published in *Ecology Letters*, implies that when patches of tropical forest lose their natural shape it could contribute to the sudden, even catastrophic, transformation of that land from trees to grass.

The Cerrado ecoregion in Brazil (Image: Wikipedia)

THEMED ISSUE LAYS FOUNDATION FOR EMERGING FIELD

In a special themed issue in *Philosophical Transactions of the Royal Society B*, SFI Omidyar Fellow Andrew Berdahl, Colin Torney (University of Glasgow), Dora Biro (Oxford University) and Peter Westley (University of Alaska Fairbanks), have gathered together contributions from a range of researchers working in the emerging field of collective movement ecology. The themed issue came about as part of an SFI working group and explores four interconnected themes: technological advances; linking individual to collective movement; linking collective movement to ecological and evolutionary processes; and the implications of understanding such processes for species conservation and management. Beyond fundamental fascination, collective movement ecology is poised to inform pressing issues of conservation and management of animals on the move.