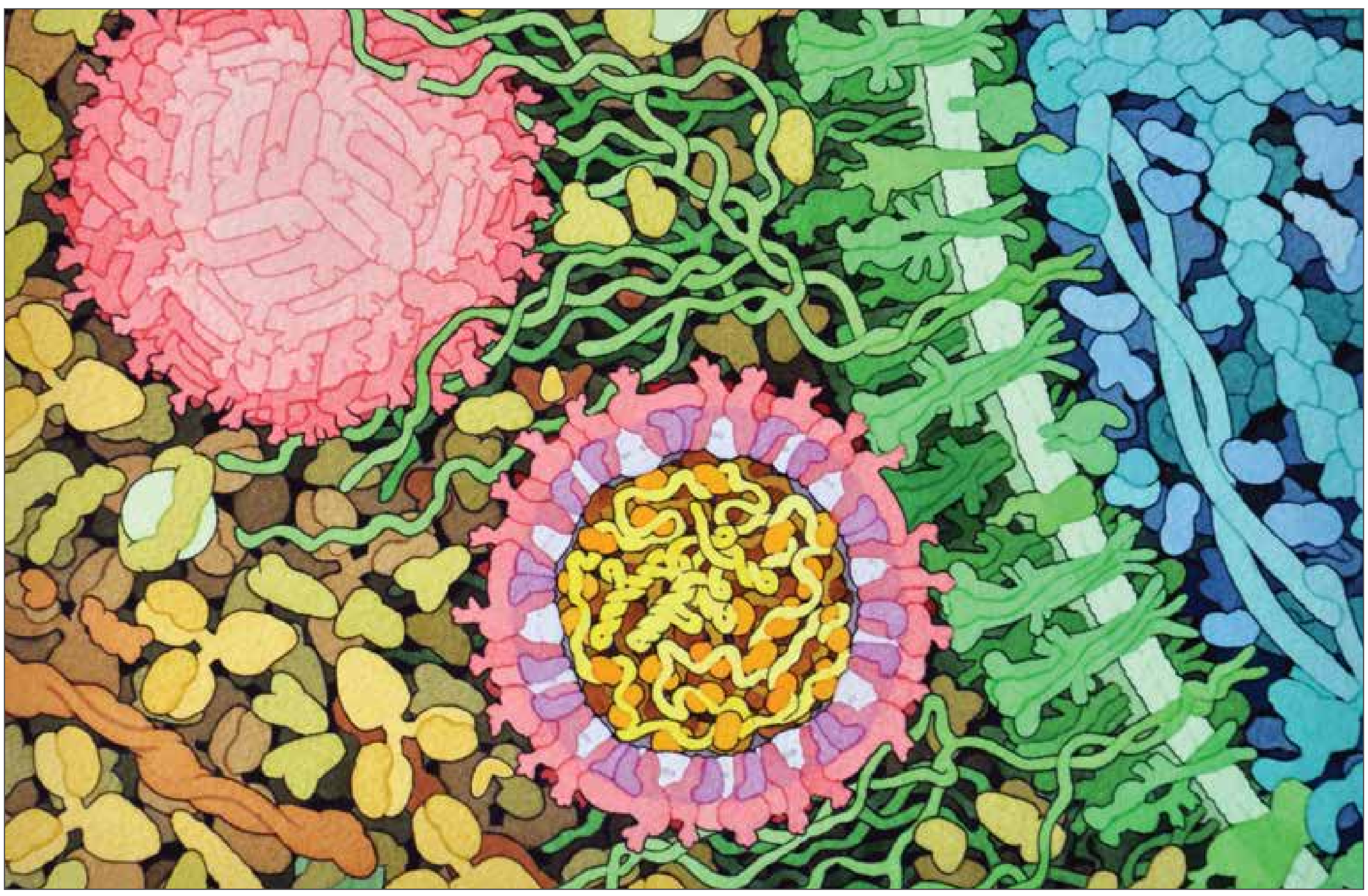
Fall 2018

Parallax

THE NEWSLETTER OF THE SANTA FE INSTITUTE



A Zika virus (pink) is shown interacting with receptors on a cell's surface. (Illustration: David S. Goodsell, courtesy The RCSB PDB "Molecule of the Month" series 10.2210/rcsb_pdb/mom_2016_5)

Approaching virology at different scales

Viruses influence life at every scale, from single-celled microorganisms up to large plants and animals. Some viruses coexist peacefully and even contribute to the evolution of their hosts, but we more often hear about the dangerous ones: pathogenic viruses that infect cells and kidnap their machinery, threatening the tissues and organs of the multicellular host. Hosts spread the viruses to other hosts, leading to widespread pandemics and public health crises.

But researchers who study viruses typically focus only on one scale, without detailed knowledge of the big picture, says molecular biologist Santiago Elena, an SFI External Professor based at the Instituto for Plant Molecular and Cell Biology, in Valencia, Spain. Molecular virologists may be unaware of the population-level effects, and epidemiologists unaware of the viral dynamics within infected individual cells, tissues and organs of single hosts.

"We're studying them at different scales but basically ignoring what is happening above and below," says Elena, whose research focuses on the evolution of viruses within plant hosts.

To start that conversation, Elena has organized Integrating Critical Phenomena and Multi-Scale Selection in Virus Evolution, a working group to be held at SFI November 19-20. He has invited leading viral ecologists, epidemiologists, and experimental molecular virologists from around the world to share experimental findings with theorists, and vice versa.

The working group is designed for the scientists to learn about virology at other scales, but Elena hopes the meeting motivates a larger, multidisciplinary effort toward a comprehensive view of how viral dynamics at one level can influence phenomena at other levels. "This is the time to start discussing whether it is possible to make all these things contribute to a new picture," he says.

Ten years after the crash, ACtioN rethinks financial risk

This fall brings a string of ten-year anniversaries. September 15: Lehman Brothers fails. September 29: the Dow Jones plummets 770 points, the greatest single-day loss to date. October 3: Congress passes the $700 billion Emergency Economic Stabilization Act, or, to many, "the bailout."

While these decennials may not inspire celebration, they beg the question: What have we learned since the financial crisis? So asks SFI's autumn meeting "Risk: Retrospective Lessons and Prospective Strategies," for members of the Applied Complexity Network (ACtioN).

"The key lesson I take away from the financial crisis is that attempts to measure risk can always fail because of the element of panic," says Bethany McLean, contributing editor at *Vanity Fair* and co-author of *All the Devils Are Here: The Hidden History of the Financial Crisis.* Crises are hard to predict, she continues, "particularly as financial markets get even more complex."

Historically, this annual meeting on finance has welcomed mavericks in economics, including Nobel laureate Kenneth Arrow. This year, McLean will be a panelist at the event, along with two Nobel laureates — Daniel Kahneman and Edmund Phelps — both of whom are known, like Arrow, for challenging traditional economic theories. Other panelists include SFI Chairman Emeritus Bill Miller and Trustees Andrew Feldstein, Bill Gurley, and Michael Mauboussin, as well as Cliff Asness, Esther Dyson, Henry Kaufman, SFI President David Krakauer, and Jessica Flack, Director of the C4 Collective Computation Group at SFI.

The meeting is timely in more ways than one. "It's a unique time in the history of markets," says Will Tracy, SFI Vice President for Strategic Partnerships. "For one thing, we're in one of the longest bull markets in U.S. history, despite political shocks that seem likely to have spooked markets in earlier times. Complexity theory helps us conceptualize the phase transitions that can cause markets

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October meetings trace signatures of life

Two October meetings at SFI aim to dig into some of the trickiest questions about life, both here on Earth, and how we might recognize it elsewhere in the universe.

Life on other worlds might have biochemistries that resemble that of life on Earth, might be built on similar molecular blocks, might behave in ways we'd find familiar. It could look like life as we know it.

Or, it might not.

It's possible that life on planets beyond our solar system — or even on bodies in our own solar system, like Saturn's moon, Titan — could host life so different from Earth's that we wouldn't recognize it. October 9-10, a working group titled "Towards Truly Agnostic Biosignatures for Astrobiology," will begin discussing ways that we might identify signs of life that are radically different from the evidence of bacteria, plants, and animals on this planet.

Life on Earth leaves behind a suite of tell-tale signs, or biosignatures, that we've come to recognize. These could be, say, fossils, traces of DNA, or an ocean sediment sample that contains compounds produced during metabolism. But even here at home, recognizing life isn't always straightforward.

"Detecting life on Earth has its own challenges: you have to rule out the possibility of false-positives where a very chemically complex but abiotic environment could look like what we see in a living world," says SFI Professor Chris Kempes, who is co-organizing the working group. "For life as we *don't* know it, we need to watch for false-negatives — for things that look abiotic but actually have life."

During this working group, participants will discuss the range of existing methods for identifying biosignatures, then think about how to expand on those to develop more general life-detection methods. "The idea is to get away from any kind of pre-conditioning, so that we're not completely tied to what we already know about life," says Kempes.

Another project asking similar questions about how life could originate and the degree of complexity that life could evolve launches with a workshop October 29-30. This will be the first annual meeting for the five-year Research Coordination Network (RCN) on the Exploration of Life's Origins, funded by the National Science Foundation and organized by Kempes and SFI President David Krakauer.

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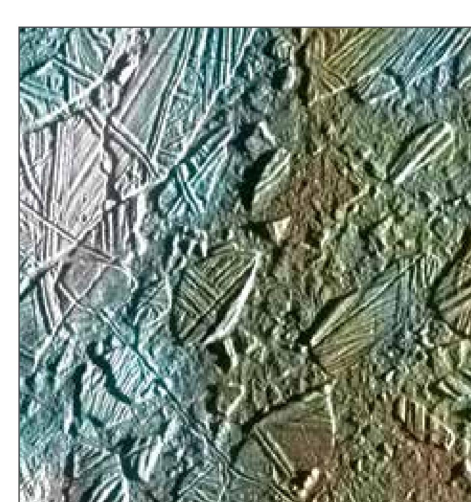

A close-up view of Europa's surface shows chaotic patterns, similar to those seen in Earth's arctic. (Image: NASA/JPL/University of Arizona)

BEYOND BORDERS

ON THE NATURE OF INVENTION

Consider the following conundrum: the more important an invention, the more anonymous are the inventors. We cannot name the inventor of language, numbers, classical architecture, logic, Chess, Go, the clock, or the wheel. One possibility is that useful objects outlive biographical influence. And it is to be expected that provenance is lost. Another more likely possibility is that most truly great ideas are collective and accretive, and the reason we cannot name an inventor is because we should be naming an invention's history.

While this reality seems at odds with much of our education and heroic cultural values, it is perfectly aligned with evolution. Any trait of significant adaptive value in a contemporary species is the agglomerate outcome of a sequence of additions and deletions contributed over the course of many generations. And while there might be a first time a given component appeared, in the initial state it was, more likely than not, underwhelming.

Consider the eye. Who or what invented it and who or what perfected it? Current evidence suggests that the master control genes regulating the appearance of photoreceptors connected to simple nervous systems are almost as primitive as multicellularity itself. The subsequent diversification of eyes — to include lenses, irises, cornea, etc. — took place over hundreds of millions of years in a variety of different lineages in many distinct environments. Nevertheless, we can still take a mouse gene and express it on a fly antenna and create a truly monstrous organ of sight that exists outside of the chronological order of things.

Notwithstanding the dominant contributions of both organic and cultural evolution to invention, we still find time, and seem to have a need, to single out an Edison, or a Curie, or a Darwin. It is more appealing to account for inventions in terms of purposeful genius than opportunistic increments. After all, we can point to Einstein's "On the Electrodynamics of Moving Bodies" (1905) and his "The Field Equations of Gravitation" (1915) as examples of apparent discontinuities with prior thought and art.

This is the essential tension of invention that exists between individual and collective creativity — one expressed in terms of the unique circumstances and abilities of an individual, and the other through the "genius of a culture." The Greeks might have invented democracy, but after all it was Homer who wrote the Iliad and the Odyssey — wait a minute — who or what was Homer?

What makes this debate so stimulating is that to understand invention we need to inquire both into the integrative and exploratory properties of individual cognition, and those same traits in a society and even in a biological lineage. This suggests that a theory of creativity might in fact exist at multiple scales, exhibiting self-similar properties that span genetics and civilization. Rather conveniently, this kind of exploration of conformability across scales, is what we do at SFI.

And this is what we shall be exploring at our *Annual Applied Complexity Network and Board of Trustees Symposium: The Emerging Frontiers of Invention* — with scholars of invention and innovation, inventors, and investors, asking how we should understand the process of invention, and how we might, as a culture, increase it.

— David Krakauer
President, Santa Fe Institute

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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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SFI IN THE NEWS

External Professors **Elizabeth Bruch** and **Mark Newman** gained significant media attention, from *The New York Times* and *Washington Post* to Scientific American and *New Scientist*, for their recent paper, "Aspirational pursuit of online dating markets," published August 8 in *Science Advances*.

Professor **Mirta Galesic** has a new column in *Psychology Today*. Her first two posts, published over the summer, cover how emotions can motivate us to collective action and how data on friends could improve election predictions.

In an article for *Slate*, External Professor **Dan Rockmore** took a logical look at the Constitution, prompted by a conundrum Kurt Gödel grappled with as he was applying for U.S. citizenship.

The *San Francisco Chronicle* and the *AP* picked up a story that ran in *The Santa Fe New Mexican* about a new documentary, "The Majesty of Music and Math," co-produced by NMPBS and Professor **Cristopher Moore**.

External Professor **Doyne Farmer** discussed economic failures and the need for new predictive technologies in a conversation with *The Edge*.

Education Advisory Board Member **Barbara Oakley** wrote in *The New York Times* that by focusing on fun rather than drill and practice in math education, we're shortchanging our children, and that this may impact girls the most.

Nature remembered SFI Co-founder **David Pines**, who died this May at age 93.

The New York Times remembered External Professor **Martin Shubik**, who died in August at age 92.

NPR featured External Professor **John Harte's** 30-year alpine meadow-warming experiment as part of a piece about climate change in Colorado.

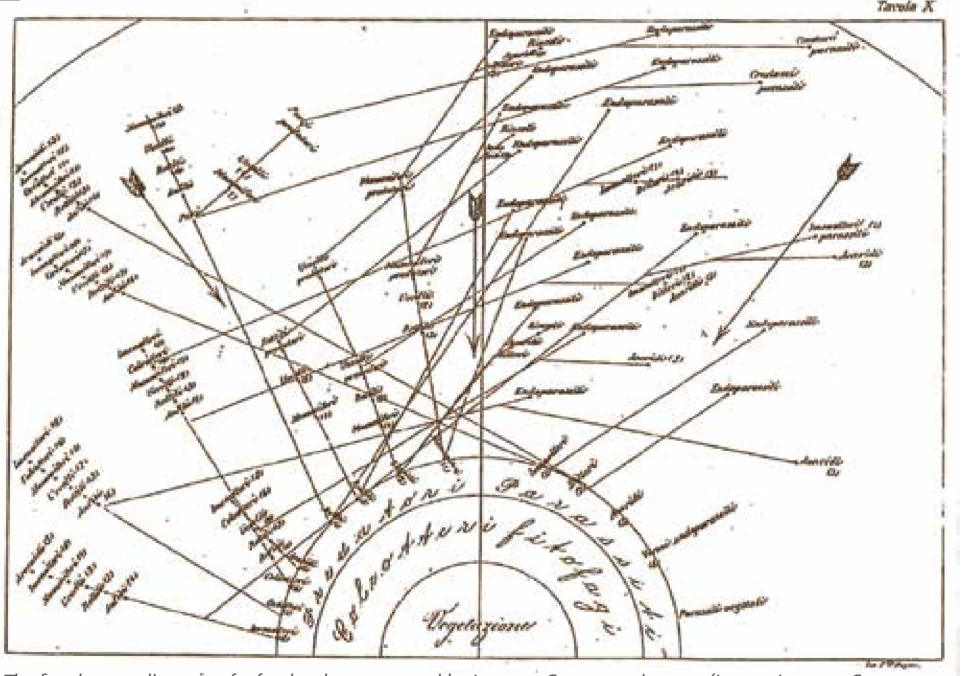
In the fifth episode of his new podcast, "Mindscape," Sean Carroll featured Professor **Geoffrey West**, and how universal scaling laws lured West away from physics.

External Professor **Amy Bogaard** commented on a recent archaeological discovery — the first evidence of bread made by hunter-gatherers in Jordan — for a story in *The Guardian*.

In a podcast for *The Santa Fe New Mexican*, Mary-Charlotte Domandi spoke with economists Wendy Carlin and Professor **Sam Bowles** about what a fair and functional economy would look like.

MIT News featured External Professor **Jessika Trancik** on shaping the future of technology.

Early-career scientists tackle frontiers of ecological network research



The first known diagram of a food web was created by Lorenzo Camerano in 1880. (Image: Lorenzo Camerano, excerpted from SFI VP for Science Jennifer Dunne's 2015 Ulam Lecture titled "The Web of Life.")

The classic ecological network is the food web, a staple of biology textbooks that pictorially describes which species eat which other species in an ecosystem. In recent years, ecological networks have evolved well beyond rudimentary cartoons to reflect the diverse backgrounds of the scientists engaged in network research. Current analyses explore topics ranging from plant-pollinator relationships to socio-ecological systems.

The growing community of scientists applying networks to environmental problems means the science is primed for a more significant role in decision-making. This November 5-7, a working group will bring early-career scientists together at SFI to imagine a collective vision for the future of ecological networks. It's the first of three meetings intended to build a community and facilitate collaboration.

"Networks are an excellent conceptual framework that can help us understand the structure and dynamics of biological communities," explains Fernanda Valdovinos, Assistant Professor of Ecology and Complex Systems at the University of Michigan and co-organizer of the working group. "They can be considered a pure scientific discipline, and at the same time, an applied concept that can help predict the effects of catastrophic events or species invasions."

Valdovinos is collaborating with Phillip Staniczenko, Research Fellow at the National Socio-Environmental Synthesis Center (SESYNC) and soon-to-be professor at Brooklyn College, City University of New York, and SFI Vice President for Science Jennifer Dunne to convene the working group.

"Several groups are tackling important questions with networks, and the time is right to get connected and accelerate innovation," says Valdovinos.

The working group is also committed to improving feedback between researchers who collect data and perform experiments in the field and those who formulate theory and design analytical tools in the lab.

"By showing how theory can inform fieldwork and how fieldwork can inform theory, ecology can be a forerunner among disciplines using networks," says Staniczenko. "We're building the next-generation of ecological network tools and techniques because we hope they will help us answer big questions in science and solve important problems in society."

Developing a theory of developmental bias

This November 14-16, SFI will host a three-day international workshop to explore the evolutionary consequences of developmental bias — the tendency of organisms to evolve some phenotypes more readily than others.

"Historically, people have tended to think that selection was what was important and tended to ignore developmental bias, but more and more experimental and theoretical evidence is accumulating for bias," says organizer Kevin Laland, a professor of biology at the University of St. Andrews and member of SFI's Science Board.

Laland is one of four organizers of the workshop, which is sponsored through a 2016 grant from the John Templeton Foundation. Attendees will include some 30 leading evolutionary and developmental biologists, ecologists, computer scientists, psychologists, paleontologists and philosophers, who will present papers and participate in discussions.

Recent studies are shedding light on how bias and selection work together. For example, despite the great diversity of colorful wing patterns in butterflies, a limited set of basic patterns emerge from the way wing "eyespots" develop. The developmental bias inherent in the way these spots form constrains butterfly phenotypes. The great diversity in nature results from natural selection acting on biased variation. It's an interaction that allows developmental processes to impose a direction on evolution, says Laland.

Phenotypic plasticity can also play a role in the ongoing interaction between bias and selection. In several animals, stress is known to induce plastic phenotypic changes that have distinct biases. These biased changes may then become stabilized by natural selection.

Owl butterfly wing spots (Image: Elena Elisseeva via Dreamstime.com)

"What's really exciting for me," says Laland, "is to get the people who are changing how we think about evolution through their work, all in one room. This will be the first time. I don't think there's ever been a workshop on bias before, so it's tremendous to get such an authoritative group of people."

Signatures of life *(cont. from page 1)*

"Origins of life is one of the most exciting questions out there," says Kempes. "The goal of these RCN meetings is to address the question: How do you go from a complex but purely abiotic world to the rise of life, and to life that evolves greater complexity over time?"

Origins of life research draws on a wide range of disciplines, from physics and chemistry to planetary sciences and paleobiology. But to make progress, researchers from these fields need opportunities for deep and meaningful dialogues, say the organizers.

As the expected 30-some workshop participants report on the major accomplishments, critiques and outstanding questions of their respective fields, they will also focus on winding back the clock on one of the most major events in the history of life: translation.

All modern life — life as we know it — has inherited the cellular machinery of translation where information stored in DNA is turned into functional proteins. This "central dogma" is one foundational aspect of biology with widespread agreement among scientists, but we don't know, necessarily, if translation is essential to the evolution of complex life.

"It becomes equally exciting if you can propose a variety of routes to complex life," says Kempes. "That begins to expand the possibilities for astrobiology."

Students and mentors in SFI's 2018 Research Experience for Undergraduates Program. Clockwise from back left, spiraling inward: SFI Prof. Cristopher Moore, Jaeweon Shin, SFI Director of Education Paul Hooper, Benjamin Anker, Alexander Ortiz, Terran Mott, Edward Huang, SFI Education Program Supervisor Carla Shedivy, Megan Bromley, Maddie Barrie, Nicolas Gort Freitas, Naika Dorilas, Oluwasunmisola Ojewumi, Mike Neuder, Alyssa Johnson, Seung Yeon Han, Sahana Subramanyam. Not pictured: Keming Zhang.

Summer in the rearview: Q&A with Paul Hooper

Summer is peak season at SFI. Our researcher population doubles, workshops and working groups overlap, and the common areas fill with students enrolled in summer education programs.

SFI Director of Education Paul Hooper, a former Omidyar Fellow and Summer School alum, had a very busy summer indeed — from leading SFI's Research Experiences for Undergraduates (REU) program and Complex Systems Summer School to organizing the first-ever Alumni Fiesta.

We asked Hooper to share some highlights, and to talk about how these programs fulfill SFI's mission to equip the next generation of complexity scholars.

Tell us about the summer REU program.

The REU program is a 10-week mentorship for undergrads with an interest in complexity science and hands-on research. We pair a student directly with an SFI mentor to co-develop a novel research project that's guided by their own interests.

At the end of the summer, participants give presentations and complete papers — but for most of these 18- to 21-year-olds, it doesn't end there. They continue to work on their projects on their own or, more often, with their mentors. Basically, we throw them into the deep end, give them lots of support, and hope they stay in the pool — and most of them do!

Any stand-out projects you can share?

One student did a semantic analysis of data from news websites and social media. They were able to infer biased speech on sites ranging from *The Atlantic* and *Mother Jones* to *Breitbart*, showing quantitative differences in levels of prejudice and hate speech.

Another student who works with Engineers Without Borders looked at the extent to which diversity of engineering teams affects success in hundreds of projects being done around the world.

Another student did a linguistic analysis of economics textbooks, showing the evolution of economic thought over the past two centuries to identify major trends, outliers, and ideas that changed the field.

What's the mission of the Complex Systems Summer School, and how was this session unique?

This is an intensive four-week introduction to complex behavior in mathematical, physical, living, and social systems, with lectures, group activities, discussion sessions, and projects.

This was the first time we held Summer School at the Institute of American Indian Arts (IAIA). With a dance circle looking out on the New Mexican sunset and beautiful contemporary native art, the space provided a new context that allowed our 80 participants from around the world to not only experience the science of SFI, but also the richness of contemporary native culture.

Complex Movements — a social activism and artist collective — joined us as the summer school's artists in residence, leading collaborative events that explored the intersection between science and social activism. Students were so engaged, they scheduled their own follow-up workshops. That was a major win.

What kind of work did the students produce?

Students pushed themselves into topic areas we hadn't seen before — important, real issues. One group, for example, inferred the prevalence and spread of malaria in Venezuela as the public health infrastructure fails. They were literally predicting malaria rates that week, when actual data may not be released for a year or two — if at all.

That's what makes my skin tingle — you put people together, give them space to mix their passions and skills, and you get amazing results.

How did the first SFI Alumni Fiesta come about?

Thirty years ago, the first Complex Systems Summer School kick-started SFI's educational programs. Since then, some 4,000 aspiring scientists have come through SFI's face-to-face educational programs. The SFI Alumni Fiesta was a chance for more than 60 of those complexity thinkers to reconnect in Santa Fe, meet people from other programs, and share some big and creative ideas — a combination reunion, conference, networking event, and collaboration space.

Can you share any Fiesta highlights?

We heard talks from David Krakauer and three superstar alums: Rosemary Braun on spectral analysis; Ryan Taylor on scaling relationships within universities; and Carlos Viniegra Beltran, who connected complexity science to major challenges in public policy.

We asked the group what they wanted to chat about with fellow alumni, then filled three whiteboards with topics, which we winnowed down to five major themes: Sustainability, Design Optimization, Research Methodologies, Community & Responsibility, and Emerging Technologies. It was a crowd-sourced intellectual discussion, overflowing with ideas, enthusiasm, and creativity. We'd never done something like this before, so it was risky — but it turned out better than I could have hoped.

After the crash *(cont. from page 1)*

to shift between states that exhibit different relationships between market risk and shocks from outside the system, such as political events or natural disasters. This type of understanding is particularly useful in counteracting our over-reliance on simpler models, such as those that still dominate most graduate level finance classes."

While the next crisis may arrive unexpectedly, we can better prepare for it by reviewing and re-thinking the complexities of financial risk.

For a longer view on risk, see "Prehistory to present" at right.

Age is not a number. Is resilience?

Many physiological and psychological systems interact to make an elderly person resilient — that is, able to withstand or recover from injury or illness over time. How to understand these systems, and how to make sense of a large volume of new data about the aging process, will be the guiding questions for the November SFI working group, "Dynamic Multi-System Resilience in Human Aging."

Led by Marcel Olde Rikkert, the chair of geriatric medicine at Radboud University Medical Center, and his colleagues, the working group is part of SFI's research theme on Aging, Adaptation, and the Arrow of Time supported by the James S. McDonnell Foundation.

A Mayan woman (Image: Murray Foubister via Flickr)

Traditionally, the aging process has been understood through the more static measure of "frailty," which offers just a one-time risk assessment of an elderly person. But recent increases in data mean that the time is ripe to view them through a complexity science lens for a richer understanding of the multidimensional, dynamic factors that contribute to resilience as we age.

"We now know that aging is more dynamic and changing over time," Rikkert says. So, "we need dynamic measures that take into account changes in elderly people."

Specifically, the increase in wearable technology means there is now more health data than ever. Smartwatches and other devices can now measure heart rate, blood pressure, temperature, and activity on an ongoing basis. In contrast, traditional methods that rely on volunteered participants are exclusionary, as people who cannot travel to medical centers to be monitored cannot participate. Moreover, they often rely on self-reported data — about, for example, levels of physical activity — and offer only occasional opportunities for measurement. With wearables, people can participate as they might in a traditional medical study, in that they are the owners of their data and can volunteer to share it with researchers, like one might give blood or be an organ donor, but the data are higher quality, richer, and produced in an ongoing manner. At the same time, complexity science tools, including multi-system and computational modeling techniques, offer new possibilities for making sense of all this new information to better understand the resilience of aging humans.

The November meeting will convene researchers from gerontology and other clinical areas of medicine with physicists, ecologists, biologists, and others who have a background in resilience. It will mark the beginning of a new kind of research in the study of aging and represent the first effort to form a network of scientists across disciplines thinking about these issues, with much research and collaboration to follow.

Hoover Dam River southwest (Image: Derwiki via Pixabay)

From prehistory to present, SFI collaborators take long view on risk

How to manage risk has vexed human societies for thousands of years. From the Ancestral Puebloans' increasing dependence on one crop — maize — to feed an expanding population to modern-day efforts to thwart power blackouts, whether a society can successfully deal with the uncertainty inherent in natural and human-made systems has profound implications for how it functions.

The upcoming SFI workshop "Managing Natural Risk in the Modern and Prehistoric World," led by archaeologist Stefani Crabtree and energy expert and SFI External Professor Seth Blumsack, both based at Pennsylvania State University, will explore the parallels between ancient and modern societies' challenges in managing risk and what lessons might be found there.

"It's about using the past in ways that can benefit us for the future," says Crabtree.

Both long-term risks, such as the droughts Ancestral Puebloans dealt with, and short-term risks, like our modern challenge of keeping the lights on during grid overloads or storms, require anticipating change in time to avert problems.

"There are huge differences in time scales, but you have this situation where you have people from very different worlds that are fundamentally asking the same question," says Blumsack. "Which is, under what conditions do these dynamic systems change, in a way where if you poke them in some way they're not going to come back? Are there ways for us to look at data and find what are essentially early warning systems of these dynamic transitions?"

The exchange of knowledge goes both ways, Crabtree adds. "We're looking not only at the data from the past but also some of the methods that Seth uses in his understanding of modern power systems to model vulnerabilities from the past, looking at those critical stages where transitions occur," she says.

While it might be unusual for an archaeologist and a power grid expert to collaborate, Crabtree and Blumsack say that after meeting for a drink to discuss their respective work, it wasn't long before they recognized that their fields could learn from one another.

"You get two people together with beer, and all of a sudden crazy stuff starts to flow," laughs Blumsack. "People like me are interested in some of the data that people like her have been able to dig up about natural resource risk. And people like her are interested in some of the tools people like me have used to detect change in dynamic systems. We said, well why don't we get a few people on each side together for a few days in Santa Fe — because where else would you do something like this — and let's see if there's something there."

The workshop will be held Oct. 22-26 at SFI.

New external faculty announced for 2018

The external faculty enrich our networks of interactions, help us push the boundaries of complex systems science, and connect us to over 80 institutions around the globe.

This year, SFI welcomes ten new External Professors.

Jean Carlson, Professor of Physics, UC Santa Barbara

James Evans, Professor of Sociology and Director of the Computational Social Science program, University of Chicago

Alan Hastings, Distinguished Professor in the Department of Environmental Science and Policy, UC Davis

Paul Hines, Professor in the Department of Electrical and Biomedical Engineering, Energy and Complexity Group, University of Vermont

Michael Kearns, Professor in the Department of Computer and Information Science; Founding Director of the Warren Center for Network and Data Sciences and the Penn Program in Networked and Social Systems Engineering, University of Pennsylvania

Willemien Kets, Associate Professor in the Department of Economics , University of Oxford

Dana Randall, Co-Executive Director for the Institute for Data Engineering and Science; ADVANCE Professor of Computing; and Adjunct Professor at the School of Mathematics, Georgia Institute of Technology

Allison Stanger, Russell J. Leng '60 Professor of International Politics and Economics, Middlebury College

Daniel Stein, Professor of Physics and Mathematics, New York University

Pamela Yeh, Assistant Professor in the Department of Ecology and Evolution at UCLA

Save the Date! Thursday, December 6, 4:00-6:00pm

WINTER TEA FOR SFI DONORS

As we bring together brilliant scholars from disparate disciplines, we've found that one of the best ways to find common ground is to bring everyone together for conversation over afternoon "tea."

This December, we invite our charitable donors to join us for our annual Winter Tea, followed by remarks by Jennifer Dunne, SFI's Vice President for Science. If you have donated, expect an invitation in the mail.

Contact Director of Advancement Shelley Winship at swinship@santafe.edu or 505.946.3678.

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RESEARCH NEWS BRIEFS

HOW LEADERSHIP ARISES IN ON-THE-MOVE ANIMAL GROUPS

When it comes to groups of animals on the move, interactions between individuals may be as important as the characteristics of the individuals themselves for determining leadership and group behavior. Collective animal movement emerges from a more complex set of interactions — it's usually not a simple follow-the-leader behavior, write SFI Omidyar Fellows Joshua Garland and Andrew Berdahl and their co-authors Jie Sun and Erik Bollt in a new paper published in *Chaos*. The authors develop an "anatomy of leadership" that relies on several principal components from how leadership arises in a group to how distributed, long-lasting, and far-reaching a particular leadership scenario is. The paper provides a set of mathematically based toy models that integrate these characteristics of leadership. Understanding how groups of animals establish leadership and move together offers important insights into their ecology and biology, but also yields algorithms for bio-inspired technologies.

FRAMEWORK UNTANGLES COMPLEX CORRELATIONS IN CELL DIVISION DATA

The dream of every cell is to become two cells, according to biologist François Jacob (1920-2013). Just how this dream is realized is the subject of SFI Omidyar Fellow Jacopo Grilli's new analysis of *E. coli* cell division data, published in *Frontiers in Microbiology*. In the paper, Grilli and his co-authors use a physics-inspired framework to examine experimental datasets on cell division. Their theoretical framework helps make sense of "a complex tangle of correlation patterns between growth-related variables," such as division times, growth rates, and the sizes of individual cells. It also offers a tool for evaluating competing answers to an unresolved question — which specific mechanisms underlie a cell's "decision" to become two cells.

NEW ALGORITHM LIMITS BIAS IN MACHINE LEARNING

Machine learning has the potential to improve our lives in countless ways, but researchers have found that the process can be unfair in certain contexts, such as hiring someone for a job. If the data fed into the algorithm suggest men are more productive than women, the machine is likely to favor male candidates over female ones, missing the bias of the input. In a new paper published in the *Proceedings of the 35th Conference on Machine Learning*, SFI Postdoctoral Fellow Hajime Shimao and Junpei Komiyama, a research associate at the University of Tokyo, offer an algorithm that ensures greater fairness in machine learning. Customers can impose constraints on the algorithm. "If you want a difference of 20 percent, tell that to our machine, and it can satisfy that constraint." Shimao says. This ability to precisely calibrate the constraint allows companies to ensure they comply with federal non-discrimination laws, adds Komiyama. The team's algorithm "enables us to strictly control the level of fairness required in these legal contexts."

ANALYZING WINNERS AND LOSERS REVEALS RANK WITHIN NETWORKS

A new algorithm called SpringRank uses wins and losses to quickly find rankings in large networks. SpringRank outperformed other ranking algorithms in predicting outcomes and in efficiency when tested on datasets ranging from teams in an NCAA college basketball tournament to dominance behaviors among captive parakeets. Former SFI Postdoctoral Fellow Caterina De Bacco (Columbia University) collaborated with former SFI Omidyar Fellow Dan Larremore (University of Colorado Boulder) and SFI Professor Cris Moore to develop the algorithm, which was published in July in *Science Advances*. SpringRank uses information that's already built into the network. It analyzes the outcomes of one-on-one or pairwise interactions between individuals. To rank NCAA basketball teams, for example, the algorithm would treat each team as an individual node, and represent each game as an edge that leads from the winner to the loser. SpringRank analyzes those edges, and which direction they travel, to determine a hierarchy. The researchers uploaded the code for SpringRank to GitHub, an online code repository, and say they hope other researchers, especially in the social sciences, will use it. "It can be applied to any dataset," says De Bacco.

THEORY AND EMPIRY MEET IN THE MIDDLE

Many ecologists and evolutionary biologists have felt that there was often a gap between theoretical and empirical research. Courtney Fitzpatrick (Indiana University, Bloomington), teamed up with ASU-SFI Fellow Elizabeth Hobson and former SFI Omidyar Fellow Caitlin Stern to see how often empirical papers cite theoretical studies, and vice-versa. It turns out that, contrary to common belief, plenty of papers do include citations across categories. In a paper published in *BioScience* in August, the team wrote that in practice, there is already considerable feedback. Review papers do this particularly well, and because they are cited frequently, offer powerful opportunities for further integration. However, there are important opportunities for even more integration. "There weren't many papers that are themselves both theoretical and empirical," says Fitzpatrick. "We know why: it's challenging! But it's also a worthwhile endeavor." SFI has also championed this approach over the past two decades, by embracing what Hobson describes as "messy, real-world datasets" and "finding ways to ground our theory in data."

RESEARCHERS OBSERVE TURING PATTERNS IN A SYNTHETIC BACTERIAL POPULATION

In 1952 Alan Turing proposed a mechanism for how patterns, like stripes on a zebra, form in biology. Since then, Turing-type patterns have been observed in nature, but scientists have generally not been able to prove that those patterns actually emerge from Turing mechanisms. SFI Science Board Fellow Nigel Goldenfeld, a professor of physics at the University of Illinois, and his coauthors recently discovered that introducing randomness into Turing's equations was sufficient to generate the patterns in an engineered bacterial population, and demonstrated it both theoretically and experimentally. As they describe in their June 2018 paper in the *Proceedings of the National Academy of Sciences*, this discovery suggests that Turing-type mechanisms can apply and offers a step forward in understanding pattern formation in nature.

UPCOMING COMMUNITY EVENTS

Predicting Chaos with Machine Learning with Michelle Girvan: SFI Community Lecture, Tuesday, November 13, 7:30 p.m., The Lensic Performing Arts Center

In recent years, machine learning methods such as "deep learning" have proven enormously successful for tasks such as image classification and voice recognition. Despite their effectiveness for big-data classification problems, these methods have had limited success predicting "chaotic" systems like those we see in weather, solar activity, and even brain dynamics. For decades, scientists have understood that the "butterfly effect" makes long-term prediction impossible for these chaotic systems. In this talk, physicist Michelle Girvan discusses how a Reservoir Computer (RC) — a special kind of artificial neural network — can draw on its own internal chaotic dynamics in order to forecast systems like the weather, far beyond the time horizon of other methods. The RC provides a knowledge-free approach because it builds forecasts purely from past measurements without any specific knowledge of the system dynamics. By building a new approach that judiciously combines the knowledge-free prediction of the RC with a knowledge-based model, she demonstrates a further, dramatic, improvement in forecasting chaotic systems.