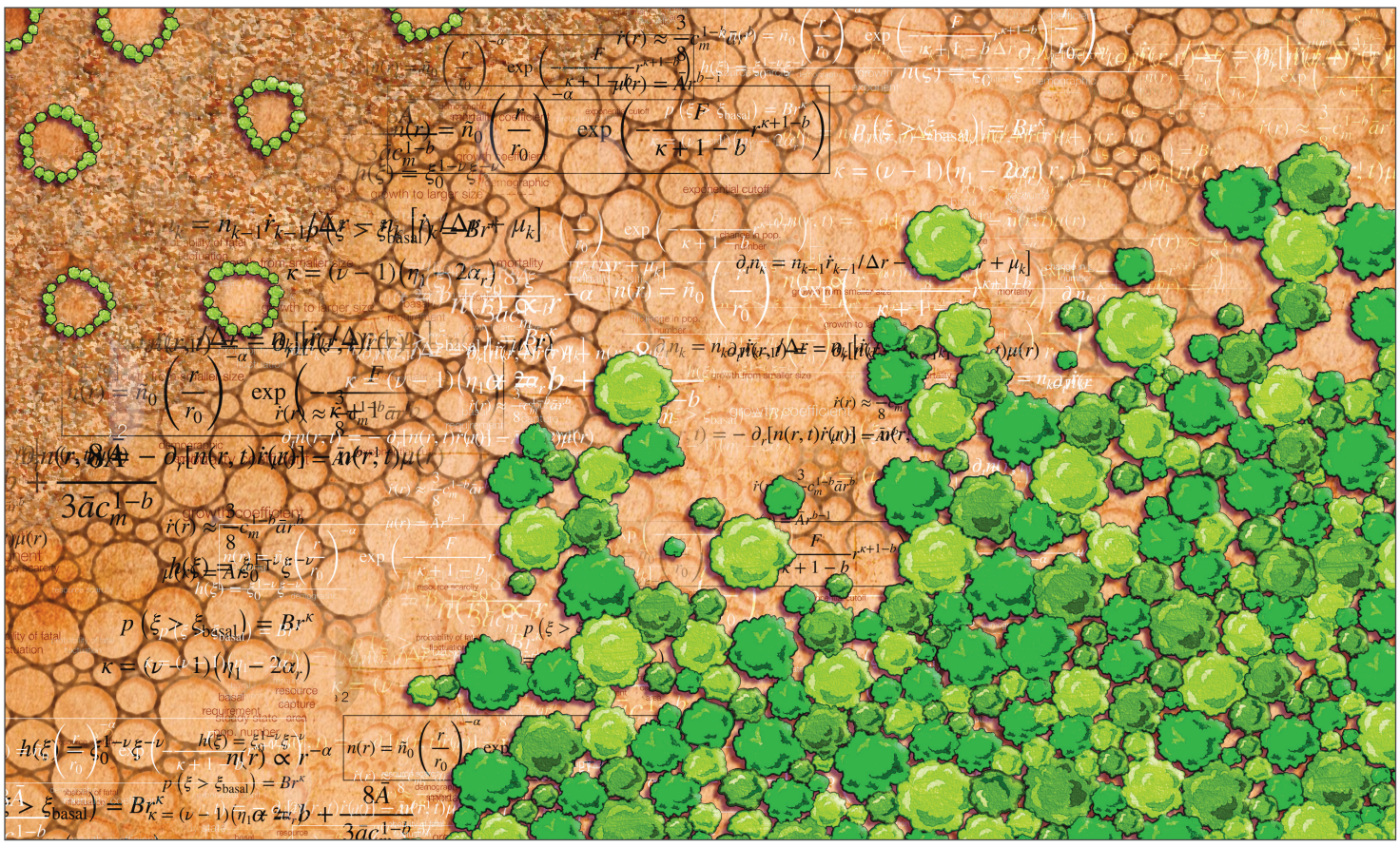
SPRING 2021

Parallax

THE NEWSLETTER OF THE SANTA FE INSTITUTE



From arid grassland to rainforest canopy, a new framework finds underlying order. (Illustration: Mesa Schumacher for the Santa Fe Institute)

The (scaling) laws of the jungle

A forest looks like a hotbed of randomness, with trees and plants scattered in wild and capricious diversity. But appearances can be deceiving, say a trio of complexity researchers at the Santa Fe Institute. Underneath that apparent messiness lurk extraordinary regularities, governed by the biological mechanisms that drive universal forces of growth, death, and competition.

In a paper published on April 13 in the journal *PNAS*, the SFI group, led by Program Postdoctoral Fellow and now Complexity Science Hub Vienna Postdoctoral Scientist Eddie Lee, describes a new framework that can reproduce those spatial and temporal patterns that emerge in places and spaces where plants grow together. The framework uses computational and statistical tools to connect metabolic principles, which control how an individual organism lives and thrives, to the diverse arrangements of trees, shrubs, and other vegetation readily observed in landscapes, forests and beyond.

"This paper goes a long way in showing how things that look arbitrary and capricious can in fact be understood within a mathematical framework," says SFI Distinguished Shannan Professor and former President Geoffrey West, who collaborated with Lee and Chris Kempes, SFI Professor, on the model.

Scientists have long sought mathematical laws that connect the similar patterns that emerge at large and small scales of existence. "If you look at the microscopic structure of multicellular life, you see a lot of the same patterns playing out," says Lee. The metabolic rate of an organism follows a power scaling law with its mass, for example. Previous attempts at establishing such mathematical laws for the assemblage of plants in a forest have been a source of vociferous debate.

In previous work, West and others have developed models that start with the metabolic constraints on a single, optimized tree to make predictions about patterns that might emerge in a community of such trees. The model accurately showed how features like growth rate or canopy size might change with plant size — and how those features might affect competition with other organisms or change the structure of the entire forest.

Kempes says that this idealized model paved the way for connecting biological principles like metabolism to mathematical, macro-level patterns, but over time researchers began to focus on how real-world situations differ in detail from that model. Not every tree or population follows the optimal rules, though, leading researchers like Lee to investigate new ways to generalize the core tenets.

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Complexity economics hits its stride

About 30 years ago, economist Kenneth Arrow and physicist Philip Anderson brought together a small group of economists and scientists at the then-new Santa Fe Institute to discuss the economy as an evolving, complex system. Stanford's W. Brian Arthur (now an SFI External Professor) was one of them.

The group, which developed a year later into a research program led by Arthur, suspected something was amiss with conventional, neoclassical economics. The problem wasn't in the math or the models; rather, they worried that the discipline was simplistic in its worldview. For the last 150 years, economic theory has depended on assumptions — made mostly for mathematical convenience — that consumers and investors think hyper-rationally — they respond to well-defined problems using optimal strategies.

This approach treats the economy like a well-oiled machine. It's elegant but not realistic, Arthur argues in an essay published recently in *Nature Reviews Physics*. The economy runs more like an ever-evolving ecology of beliefs, principles, and behaviors, Arthur writes, populated with actors whose decisions — often necessarily based on incomplete information — feedback into the system itself. It's neither neat nor deterministic; it's dynamic and complex. It's "always creating itself, alive and full of messy vitality."

In those early days, SFI was a community of researchers exploring complexity in its many guises: In the dynamics of traffic or the behaviors of individual cells in the immune system. In these systems, individual elements interact and produce patterns, which in turn influence systems and cause the elements to change or adapt.

Such characteristics describe economies as well, Arthur recognized. Over the years, he and his colleagues developed the core tenets of complexity economics, which eschews the idea that people act rationally, or that the economy has an equilibrium state. By using tools including agent-based, computational modeling and

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Insights for COVID-safe school reopening

Since early in the COVID-19 pandemic, parents, teachers, and school administrators have faced difficult questions regarding when and how to safely reopen for in-person learning. During the 2020-2021 fall semester, school districts around the United States navigated their reopening plans — many opting for exclusively online learning or hybrid models — with little data on how SARS-CoV-2 spreads among children or how in-person learning would impact transmission in the schools' communities. A new study in *The Journal of School Health* joins a growing body of evidence that, with appropriate measures, there are ways for schools to safely reopen.

In this study, scientists analyzed data from two large, independent k-12 schools that reopened for in-person learning last fall. The results suggest that, with robust universal testing and mitigation measures, in-school transmission can remain low even as the surrounding community transmission rates rise.

The two schools in this study, one located in the southeastern United States and the other in the Mid-Atlantic, both conducted regular testing of all students and staff and required mitigation measures like mask wearing, social distancing, and ventilation and air filtering. When positive cases were detected, the schools and local health authorities did contact tracing to determine how the person was likely exposed.

Throughout the semester, both schools saw cases, but the rate of transmission was 0.5 or lower. "Because each infection causes less than one additional infection on average, an infection doesn't spread much within the school," says SFI Professor Michael Lachmann, who co-authored the study with SFI External Professor Lauren Ancel Meyers (University of Texas at Austin), Darria Long Gillespie, Stephen Redd, and Jonathan Zenilman. "If we could get a rate of 0.5 in the community, that

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Students with protective masks sitting in school desks in their classroom. (Photo: miljko/iStock)

BEYOND BORDERS

FRACTAL ORGANIZATIONS AND FRACTAL FACULTY

By all accounts Plato was a zealot for geometry. In *The Republic* he wrote: "We must order in the strongest possible terms that the men of your Ideal City shall in no way neglect geometry." The source of Plato's advocacy relates to his use of geometry — in particular ideas bearing on the indivisibility of lines — as a metaphor for the parts and the whole that define Being. And additionally as a means of establishing a correspondence between the rigors of mathematical analysis and the more pliable dialectical reasoning in his own work.

Subsequent contributions in geometry moved away from Platonic foundations toward simultaneously grander and more grounded topics, such as establishing the true shape of the universe. *The Almagest* of Ptolemy, building on Euclidean ideas of space, established a spherical geocentric model that was accepted for over 1200 years. Not until Gauss in the 18th century and Lobachevsky in the 19th did non-Euclidean geometry emerge as alternative models. And in the 1970s Benoit Mandelbrot introduced fractal geometry, building on earlier ideas from Weierstrass and others, to capture ideas of self-similarity such that an equivalent amount of structure can be found at all spatial scales.

I like using fractal geometry as a metaphor for organizations the way Plato used Euclidean geometry as a metaphor for being and society. For Plato the line was the atom of being. And a variety of geometric constructions based on the line served as analogs for society and civilization. The fractal — when deployed this way — might be used to suggest that smaller scales or parts need not be thought of as lesser or diluted versions of larger scales.

The Santa Fe Institute is smaller than a large university department but not lesser or lacking in structure. How is this possible? The answer is that SFI is a beautiful example of a fractal-like organization that preserves at a small scale most of the structure one finds in far larger organizations. And with the advantage of greater cost efficiency.

The idea for fractal faculty is a natural extension of this concept. Whereas faculty at universities exist at preferred scales of both space and time (appointments to a physical department with labs of a given size and in residence for a given duration of tenure, etc.), a fractal faculty member can be scale-invariant and live at many scales of space and time, from months to years and consequently at many spatial scales spanning New Mexico to Madagascar!

As a result of a campaign kicked off with a very generous multi-million matching gift provided by Jim Pallotta, followed by Elizabeth and Chris Davis, Bill Gurley, Jerry Murdock, and several other members of the SFI Board of Trustees, we are now hiring fractal faculty. Melanie Mitchell was the first Davis Professor. I am also delighted that Sean Carroll will be joining us soon as the second fractal faculty member. And there are several wonderful fractals lining up along the horizon.

It is always nice when the problems that one studies and their solutions can be recruited to provide the basis for new ideas about organization. SFI has long lived according to the principles of discrete geometry described using networks and now we are putting the fractal to work as a model for a scale-free researcher.

— 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 MEDIA

In an article about diversifying and modernizing the teaching of economics, *The Economist* cited a paper by SFI Professor **Sam Bowles** and External Professor **Wendy Carlin**. It lauded their CORE economics curriculum, which they created with fellow SFI contributors **Simon DeDeo** (External Professor), **Marion Dumas** (former Omidyar Postdoctoral Fellow), **Suresh Naidu** (External Professor), and **Rajiv Sethi** (External Professor).

Melanie Mitchell, SFI Davis Professor of Complexity, was interviewed by NPR's *WHYY*, in a podcast about how artificial intelligence mimics human language. In the interview, Mitchell describes an early AI she and her fellow SFI postdocs created in the 1990s to generate publication titles for the fictional SFI scientist "Ian Malcom" from the Jurassic Park series.

SFI External Professor **Ricard Solé**'s recent paper on using synthetic biology to create Turing patterns, the subject of an SFI working group (see p.6), was featured in *Ars Technica*.

IFL Science reported a new paper on the post-parenthood productivity gap between women and men in academia. The paper's co-authors included SFI External Professor **Aaron Clauset**, Professor **Mirta Galesic**, and lead author **Allison Morgan** at CU Boulder.

SFI Professor **Cris Moore** and External Professor **Melanie Moses** were featured in the *Santa Fe New Mexican*, *Yahoo News*, the *Santa Fe Reporter*, and KSFR's *Living on the Edge* radio show for their virtual discussion of the film "Deprogramming Bias," in partnership with Center for Contemporary Arts Santa Fe.

SFI Professor **Michael Lachmann** was quoted in the *Los Angeles Times* and in *Yahoo News* in articles about COVID-19 mitigation strategies for schools.

Distinguished Shannan Professor **Geoffrey West** appeared on the BBC's "Pyrotechnic History of Humanity" to discuss how cooking food over fire allowed humans to grow their metabolically intensive brains.

Bloomberg featured work by External Professor **Simon DeDeo** on conspiracy theories, and his team's Bayesian framework for evaluating explanations.

Smart thinking about intelligence

What makes something intelligent? Where is intelligence to be found? How is intelligence studied? SFI researchers Melanie Mitchell and Melanie Moses organized a virtual conference in March that aimed to answer questions about the foundations of intelligence from areas as diverse as philosophy to evolutionary intelligence and complex information processing.

"We're trying to get a sense of where people are when thinking about what intelligence is, what's important to study, what are the big open questions," says Mitchell, who is SFI's Davis Professor of Complexity.

Mitchell cites AI pioneer Marvin Minsky, who referred to intelligence as a "suitcase word"— one filled with all kinds of definitions. There's human intelligence and the artificial intelligence of robots, but there's also intelligence in swarms of ants and maybe even a kind of intelligence in something like a market. There's evolutionary intelligence as well as social intelligence.

For three hours every morning during the week of March 15, presenters at the meeting discussed these topics, trying to puzzle together just what intelligence means. Each presenter spoke for 30 minutes, followed by 20 minutes of discussion and questions, to facilitate the kinds of conversations that would usually happen outside of talks at an in-person conference. Speakers included SFI External Professors, Resident Faculty, Postdocs, and researchers from beyond SFI — researchers like Daniel Dennett, Ricard Solé, Stephanie Forrest, and Alison Gopnik, whose fields of study span philosophy, physics, biology, computer science, and psychology.

Ants use collective intelligence to create a living bridge. (Photo: Igor Chuxlancev\ wikimediacommons.

"We're inviting basically everyone in the SFI community," says Mitchell. She hoped the meeting would get people out of their narrow research areas and think about the big picture.

The goal of this meeting was not to settle the matter and find answers to all of these questions about intelligence, but to forge interdisciplinary collaborations. The meeting was supported by a National Science Foundation "planning" grant, with the aim to develop a full proposal for the NSF's AI Institute program.

"We hope to generate ideas in these workshops that will inform the full proposal writing," says Moses, an external professor at SFI. "We hope that a subset of the participants will also be co-PIs or personnel on the full proposal."

Five other meetings are planned for 2021-2022, and depending on COVID conditions, some may be in person.

Roundtable grapples with market volatility

A famous saying, often attributed to the early twentieth-century economist John Maynard Keynes, is "the market can remain irrational longer than you can remain solvent."

That's where seasoned investors find themselves after a year in which the stock market recovered from a pandemic-induced crash to reach record highs and amateur investors on Reddit drove shares of video game retailer GameStop up 1500% over a two-week period.

The unfortunate reality is that the regulations governing today's financial markets weren't designed to deal with a world where the valuation of GameStop, AMC, Nokia, and other equities can be challenged by a coordinated effort on the part of amateurs on the internet.

"The Wall Street Bets phenomena is just the latest in a series of events that show how communities formed through new technologies are altering our belief dynamics," said Will Tracy, Vice President for Applied Complexity at the Santa Fe Institute. "Radical disagreements over ground truths are becoming the new norm."

At SFI's Applied Complexity roundtable in March, SFI External Professor and MIT economist Andrew Lo spoke about "market adaptation" and applied a complex ecological and evolutionary lens to the market's behavior under COVID. This set the stage for breakout discussions focusing on the nature of the GameStop phenomenon and how emergent engineering could help human social systems become more resilient in the face of changing environments.

One example of an emergent engineering approach that's already used to regulate financial markets is a rule for pausing trading when signs of a massive drop are detected. SFI Professors Jessica Flack and Melanie Mitchell described this stock market "circuit breaker" in a 2020 article for *Aeon* magazine. They wrote that an even more explicit approach to the complex problem of timescale separation would be to slow down trading by limiting the magnitude or frequency of trades during a crisis, then allowing trading to return to normal when the environment is more predictable.

> "The Wall Street Bets phenomena is just the latest in a series of events that show how communities formed through new technologies are altering our belief dynamics."
>
> —WILL TRACY

While their example may seem simple at first glance, designing systems that excel under uncertainty is not easy.

One of the major challenges is developing a greater understanding of why people in a network, such as the users of the Wall Street Bets subreddit, make the decisions that they do.

This is an area of investigation particularly well suited to the study of "belief dynamics," another emerging field of complexity science that SFI researchers are advancing by creating quantitative frameworks to make sense of social survey data on a wide array of topics.

At the 12th annual meeting on Risk and Applied Complexity, co-hosted by SFI and the Swiss bank UBS last fall, SFI External Professor Simon DeDeo discussed how recent work in cognitive science has uncovered a diversity of explanatory values, or dimensions along which people judge explanations as better or worse.

His work in the area could ultimately help scientists paint a clearer picture of the drivers behind phenomena like the Wall Street Bets incident, and is already shedding light on the formation of conspiracy theories and extremist ideologies online.

"No one sticks $10,000 of their money into something by accident. They're doing it because they have a story about the way the world works. And in the case of GameStop, that story is a shared one, that they've developed with others in a hothouse online," said DeDeo, who is also an assistant professor in the Department of Social and Decision Science at Carnegie Mellon. "We are interested in uncovering these stories, understanding their appeal, and seeing how people use them to make decisions."

The intersection of belief dynamics and emergent engineering will be addressed again at SFI's annual Fall Symposium on November 5–6, 2021.

Accounting for the gaps in ancient food webs

If you want to understand an ecosystem, look at what the species within it eat. In studying food webs — how animals and plants in a community are connected through their dietary preferences — ecologists can piece together how biomass and energy flow through an ecosystem. Studying ancient food webs can help scientists reconstruct communities of species, many long extinct, and even use those insights to figure out how modern-day communities might change in response to climate change and other disturbances. There's just one problem: only some species left enough of a trace for scientists to find eons later, leaving large gaps in the fossil record — and in researchers' ability to piece together the food webs from the past.

"When things die and get preserved as fossils, all the stuff that isn't bones and teeth and shells just decays," says SFI Vice President for Science Jennifer Dunne, a veteran food web researcher. "Organisms that are primarily soft-bodied, they usually just disappear from the record altogether."

A new paper by paleoecologist Jack Shaw, a Ph.D. student at Yale University who led the study, Dunne, and other researchers shines a light on those gaps and points the way to how to account for them. "The missing components of the fossil record — such as soft-bodied organisms — represent huge gaps in understanding ancient ecology, but we haven't thought extensively about how those gaps are affecting our inferences," Shaw says. "We're taking the fossil record at face value without critically thinking about how face value might not be robust and accurate."

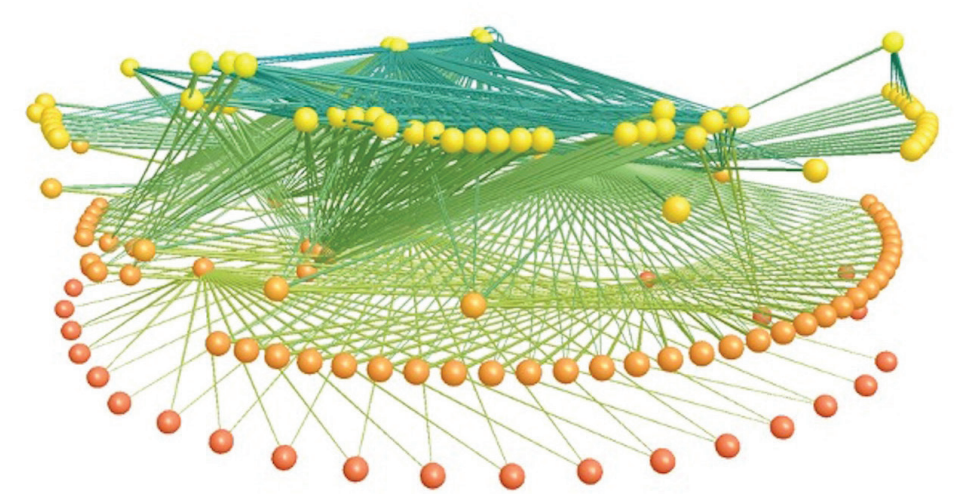
Focusing on the absence of soft-bodied taxa in the fossil record, the study, published in *Paleobiology* on January 14, notes that accounting for these data gaps is vital for forming a more accurate picture of ancient food webs. By only looking at fossilized taxa, without accounting for the loss of soft-bodied organisms to the sands of time, for example, researchers might make the mistake of assuming the ecological community was structured differently, and was less stable, than it actually was.

But by drawing on network theory, the researchers were able to show that the inclusion of soft-bodied organisms is vital for realistic depictions of ancient food webs. They found that ecological differences between soft- and hard-bodied taxa appear in the record of an Early Eocene food web, but not in much older Cambrian food webs, suggesting that the differences between the groups have existed for at least 48 million years.

"Geologists and biologists assume that soft-bodied and hard-bodied things have distinct life habits — where they live or who they eat — but we actually quantify it here using network analysis," Shaw says.

He and Dunne hope the study, which emerged out of a 2019 SFI Complex Systems Summer School project, will help strengthen future research in the burgeoning field of ancient food web reconstruction. "This work is really important, because it's grappling with some of the fundamental uncertainty relating to the fossil record," says Dunne.

"The methodology can be applied to various other types of biases," not just the soft-bodied-organism-related bias, Shaw notes. "We're hoping to start being more critical of ancient food webs and perhaps opening them up to being more robust. A better grasp on how ancient food webs were affected by perturbations will allow us to make better predictions of what future ecosystems may look like."



The Burgess Shale food web is one of eight ancient food webs that were analyzed for similarities. (Figure: J. Dunne)

SFI shines in 'golden age' of social science

Crossing disciplines, collecting new data in unconventional ways, and establishing a common language have long been hallmarks of scientific culture at the Santa Fe Institute. Now these same practices are spurring a "golden age" in social science, to which SFI researchers have made outsized contributions over the past 12 years, according to a perspective piece published February 2 in *PNAS*.

"It's extraordinary how many SFI scholars appear in this review when you think about what a tiny place the Santa Fe Institute is," says SFI Professor Sam Bowles, whose work was highlighted along with that of other SFI-affiliated researchers including External Professor Robert Boyd, External Professor Herb Gintis, Former Omidyar Fellow Paul Hooper, External Professor Matthew Jackson, External Professor Suresh Naidu, former External Professors Steve Strogatz and Duncan Watts, longtime collaborators Monique Borgerhoff Mulder and Joseph Henrich, and dozens of other scientists not affiliated with the Institute.

The review, titled "The golden age of social science," was penned by Caltech researchers Anastasia Buyalskaya, Marcos Gallo, and Colin Camerer. They argue that the interdisciplinarity of the golden age, evidenced by citations to and from outside fields and by multiple leaders on NSF grants, is enabling scientists to explore more difficult questions than were previously possible. They write:

"Scholars will increasingly focus on difficult questions — ones that may have been avoided historically because their complexity made them impossible to tackle from one discipline alone — and social science will be more impactful together than the sum of any one subdiscipline working on its own."

Bowles credits much of SFI's contributions to the social sciences to a decision by the late SFI President and co-founder George Cowan, who in 2003 endowed the Institute's Behavioral Sciences Program.

"That was 18 years ago," says Bowles," and I wish George were around today. SFI is on the map as a place that does top-level social science, punching way above our weight compared to the big universities."

RESEARCH NEWS BRIEFS

Pronghorns on Seedskadee National Wildlife Refuge (Photo: Tom Koerner/USFWS)

ANIMAL AGGRESSION DEPENDS ON RANK WITHIN SOCIAL HIERARCHIES

The more animals know about each other, the more they may be able to optimize their aggression. New research, published in *PNAS*, offers the first big-picture look at information in these animal systems. Using a new computational method, former ASU-SFI Complexity Postdoctoral Fellow Elizabeth Hobson, SFI External Professor Simon DeDeo, and collaborator Dan Mønster of Aarhus University in Denmark examined existing data on aggression — the earliest from a 1934 pigeon study — in 172 social groups across 85 species in 23 orders, looking for social dominance patterns. They found three main aggression strategies employed by individuals: simply fighting any lower-ranked opponents; specializing in fighting "close competitors" ranked just below themselves; and bullying opponents ranked much lower.

The majority of the groups fell into the first category, where aggression could be explained by animals following a basic dominance hierarchy, but several groups used the more information-rich close competitors or bullying strategies to fine-tune their choice of opponents.

Hobson says she hopes the study will inspire other researchers to look at how social information is used within and across species. This could provide a foundation for answering even bigger questions about how social complexity arises in animals, and how animals evolved the cognitive skills to enact these social dominance patterns.

Read the paper at doi.org/10.1073/pnas.2022912118

THE CLOUD-LIKE GEOMETRY BEHIND CITY SCALING

New research in the *Journal of the Royal Society Interface* reveals the geometry behind predictable scaling relationships that apply to cities worldwide.

The paper, by Carlos Molinero and SFI External Professor Stefan Thurner of Complexity Science Hub Vienna, explains the fractal origins of two types of urban scaling laws, first documented by SFI researchers in 2007.

The first law, "sublinear scaling," is for systems that deliver resources. It means a city with a large population needs only ~80% as many roads, power lines, and gas stations per person as a city half its size. The second, "superlinear scaling," applies to outputs of socioeconomic activity. It means a large city produces ~120% more wealth, patents, crime, pollution, and disease per person than a city half its size.

To investigate, Molinero and Thurner used open data on the height of buildings from more than 4,700 cities in Europe to map where people live. The scientists assigned a dot to every person living in a building. Together, these dots form sort of a "human cloud"— a self-similar fractal within a city.

Using the human cloud, the researchers were then able to determine the fractal dimension of a city's population: They retrieved a number that describes the human cloud in every city. Similarly, they calculated the fractal dimension of cities' road networks.

Read the paper at doi.org/10.1038/s41583-020-0363-6

LOW-WAGE WORKERS AT RISK OF JOB LOSS DUE TO AUTOMATION

In a study published in the *Journal of the Royal Society Interface*, SFI External Professor Doyne Farmer, first author Maria del Rio-Chanona, and their colleagues at the University of Oxford explore the impact of automation on low-wage workers. The COVID-19 pandemic is accelerating the pace of automation, and they determined that low-wage workers face a double-whammy of being more likely to lose their jobs to automation and less likely to have the skills to switch to newly created jobs.

This work is based on a data-driven model created to analyze how workers move through an empirically derived occupational mobility network in response to automation scenarios. By identifying workers most at risk of long-term unemployment, the researchers' model can better target worker support and retraining programs to help low-wage workers adapt to the changing economy.

Read the paper at doi.org/10.1098/rsif.2020.0898

YOU CAN HAVE YOUR NICHE CONSTRUCTION AND FORGING THEORY, TOO

A review paper published in *Evolutionary Anthropology* reconciles competing approaches in the sciences of human behavior. Co-authored by SFI Applied Complexity Fellow Michael Price and Elspeth Ready of the Max Planck Institute for Evolutionary Anthropology, it examines two branches of evolutionary science that are often regarded as rivals and presents a general framework to reconcile them.

The authors hope it will serve as a guide to evolutionary human scientists, especially graduate-level archaeologists and anthropologists.

Read the paper at doi.org/10.1002/evan.21885

MOTHERHOOD PLAYS KEY ROLE IN WHY WOMEN PUBLISH FEWER PAPERS

Despite strides in family-leave offerings, and men taking a greater role in parenting, women in academia still experience about a 20% drop in productivity after having a child, while their male counterparts generally do not, according to new research.

A study in the journal *Science Advances*, co-authored by SFI Professor Mirta Galesic, External Professor Aaron Clauset, former Omidyar Fellow Daniel Larremore, first author Allison Morgan, and collaborators at CU Boulder suggests that persistent differences in parenting roles are the key reason that men tend to publish more research papers than women. Because publishing is closely linked to promotion, this gender gap could have long-term impacts on what academia looks like in the future.

Read the paper at doi.org/10.1126/sciadv.abd1996

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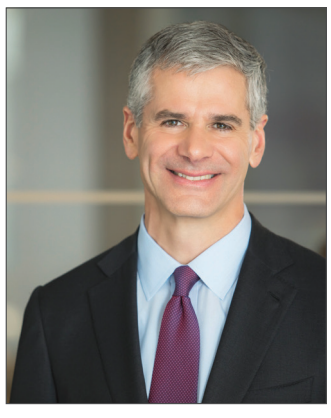
Mauboussin retires as Chair of SFI Board of Trustees



Hailed as "one of Wall Street's most creative and influential minds," investment strategist Michael Mauboussin, Head of Consilient Research at Counterpoint Global, Morgan Stanley Investment Management, retired from his 8 1/2-year chairmanship of SFI's Board of Trustees following the board's bi-annual meeting in May.

Mauboussin has often, in media interviews, credited complex systems science for inspiring his view of market behavior. During his tenure as Chair, which began in November 2012, he helped keep that science afloat in the aftermath of an economic recession,* and through a global pandemic.

"I could not wish for a more thoughtful and caring collaborator than Michael as we worked through the financial and institutional complexities of life in 2020. Michael is a testament to someone who both understands the mysteries of economic systems and someone who cares deeply about the basic science at SFI as well as its researchers. Without Michael things could have worked out very differently last year," says David Krakauer, SFI's president, who is also the William H. Miller Professor of Complex Systems.

Under Mauboussin's leadership, SFI hasn't merely weathered the financial challenges of the past decade; it has flourished under them. In partnership with Krakauer, Mauboussin has helped guide SFI's expansion to a second campus in Tesuque, NM, and helped tighten the board's membership to make it even more efficient while simultaneously guiding it toward greater diversity than at any time in SFI's history.

He has worked tirelessly to eliminate "to-be-raised" funds in the Institute's budget, and by managing its investments and keeping it financially nimble, has helped maintain SFI as a haven where researchers can focus on big ideas rather than on securing funding.

Even as he retires from his chairmanship, Mauboussin remains an active Trustee on the Board. He has pledged to support Katherine Collins and Ian McKinnon as they transition into their new roles as Chair and Vice Chair.

Krakauer is quick to point out that "just as SFI science is fundamentally collaborative, so is running an institute. As far as I am concerned Michael has been my partner from day one, and we spoke frequently about both challenges and opportunities. I feel very fortunate to have worked with someone with the intellectual caliber and professional ethics of a Michael Mauboussin. I have learned a great deal through our partnership."

"SFI science has deeply influenced me professionally and personally and it has been an honor to serve SFI's board and broader community. As President, David Krakauer has infused the institute with vision, energy, and rigor, and it has been my pleasure to work closely with him and the rest of the leadership team. I look forward to continuing as an engaged board member, and have every confidence that Katherine and Ian will build on the Institute's strength."

*Mauboussin replaced former Chair Jim Rutt, who helped to see the Institute through the Great Recession.

Collins and McKinnon to lead BoT

Katherine Collins has been elected Chair and has appointed Ian McKinnon as Vice-Chair of the Santa Fe Institute's Board of Trustees. Their three-year appointments began May 3, 2021, following the board's bi-annual meeting.

Katherine Collins is the first Head of Sustainable Investing at Putnam Investments and Founder of Honeybee Capital, the precursor to Honeybee Capital Foundation. She is also the first woman to chair SFI's Board of Trustees since the institute's founding in 1984.

Collins first came to SFI in the late 90s through SFI's Applied Complexity Network. She was a new portfolio manager at Fidelity Investments, a member of the Applied Complexity Network (then known as the "Business Network"), when she attended a meeting on the topic of collective decision-making by honeybees. She was fascinated by speaker Thomas Seeley's account of how the honeybees dispatch their most senior members to gather information, then use that information to inform a collective, democratic decision.

This inspired an evolution in Collins' life and her approach to investing. After rising to the rank of Head of Equity Research, Collins departed Fidelity. She went on to enroll at Harvard's divinity school, starting her own investment research firm, Honeybee Capital, while earning her degree. Honeybee also joined the Applied Complexity Network, and in 2013, Collins was elected to SFI's Board of Trustees.

She now uses biomimicry and systems-thinking to inform her work at Putnam, where she has been leading sustainable investment research and ESG (Environmental, Social, and Governance) strategy since 2017.

"The deep understanding that's come through my affiliation with SFI is not only about individual systems, but the relationships between those systems," Collins says. "Much of our professional work does the opposite — it pulls you to be more and more narrow over time. And so for me, in addition to the substance of the science at SFI, the SFI culture of exploration and connection has encouraged me to keep that broader interconnected view, no matter what the question or the context."

"For me, in addition to the substance of the science at SFI, the SFI culture of exploration and connection has encouraged me to keep that broader interconnected view, no matter what the question or the context."

—KATHERINE COLLINS

When **Ian McKinnon** was first introduced to the Santa Fe Institute in 2007 by legendary investor Bill Miller (Former Chairman of the Board and Life Trustee at SFI), he knew he "had to go visit the campus as soon as possible."

Raised by a father who was both a Justice on the New Mexico Supreme Court and a professional jazz drummer, a mother who was a poet of significant acclaim, and a grandfather who helped to found a major medical center in Albuquerque, McKinnon naturally resonated with SFI's trans-disciplinary mindset.

"I was immediately taken with the notion that attacking difficult problems through a trans-disciplinary prism is vastly superior to the narrow academic silos we typically employ," he says. "And the fact that all of this cutting-edge, fundamental research was taking place in New Mexico, the state where both my wife, Sonnet, and I, were raised — it was incredibly meaningful."

As a successful hedge fund manager, first for Ziff Brothers Investments where he retired after nearly 20 years as Managing Partner and now for Sandia Holdings, his family office, McKinnon maintains that investing is an inherently trans-disciplinary activity. He is firmly convinced that some of the fundamental tenets of complexity science, especially the emphasis on agent-based incentives and feedback loops, have significantly enhanced his investment approach and methodologies.

At the same time, he is also the first to say that (like any complex adaptive system), his investing strategies continue to evolve to this day!

The McKinnons are long-time supporters of SFI and have made multiple large gifts to the Institute's education programs, and to expand fundamental research and core science activities like the workshops and working groups for which, McKinnon notes, "SFI is justifiably famous."

SFI President David Krakauer, who is also the William H. Miller Professor of Complex Systems, says he is delighted to be working with Collins and McKinnon in their new leadership positions.

"SFI has been incredibly fortunate to have Katherine and Ian on the board," Krakauer says. "At this point, they are both indispensable members of the SFI family and friends to whom I turn for advice and insight. The new roles that they are assuming give us all tremendous confidence in the viability and future of the institute. Both Katherine and Ian are science nerds like the rest of us at SFI and bring to their new roles a passion for ideas and a deep understanding for how insights from the various fields of complexity can inform both professional and intellectual life."

Darla Moore joins SFI Trustees

Darla Moore has been elected to the Santa Fe Institute's Board of Trustees, with a three-year appointment beginning in May 2021. Moore is the Founder and Chair of the Palmetto Institute, a not-for-profit think tank that aims to raise per capita income in South Carolina. She is also the former Managing Director of Chemical Bank and the former President of Rainwater Inc., a private investment firm. She currently serves on the board of The Shed, a cultural institution that fosters innovation and creativity for a more equitable society.

With a long and storied career in business and finance, Moore has served on the boards of many organizations, including Martha Stewart Living Omnimedia, the National Advisory Board of JP Morgan, New York University School of Medicine, and Teach for America. She was the first woman to land on the cover of *Fortune* and was named corporate America's most feared female activist in the magazine's first 50 Most Powerful Women ranking. In 2012, Moore shattered another glass ceiling as one of the first two female members, along with Condoleezza Rice, of the Augusta National Golf Club.

Moore is well known for her philanthropic work. In 1998 she made a $25 million donation to the business school at the University of South Carolina, which was subsequently renamed the Darla Moore School of Business — the first business school in the US to be named after a woman. She has also given substantial financial gifts to Clemson University's school of education, USC's McNair Center for Aerospace Innovation and Research, and Claflin University's music department. Moore was awarded South Carolina's highest civilian honor, the Order of the Palmetto, in 1998 for her contributions to the state.

"Throughout my career, I've been committed to organizations that work to build a more equitable society," Moore says. "Doing that requires the kind of deep understanding of systems — and how they work together — that only complexity science provides. I'm proud to be part of the Santa Fe Institute, where researchers are demystifying some of the world's most pressing issues, including the causes and impacts of inequity, to uncover practical solutions."

Complexity approach to pandemic policy shows early benefits

Even as vaccines begin to roll out in large numbers, new coronavirus variants present tough challenges for leaders in setting health policy. With the TRACE (Testing Responses through Agent-based Computational Epidemiology) simulation model, the City of St. Louis now has help.

Since we first reported on TRACE last July, SFI External Professor Ross Hammond, a senior fellow in Economic Studies at the Brookings Institution, along with a team at Washington University, have been using the model to help policymakers at different levels of scale manage the pandemic uncertainty — addressing both knowns and unknowns to produce multiple potential outcomes for any policy option. And early results of the model make the benefits of agent-based modeling clear.

A petri dish for policy

Hammond and his colleagues pitch TRACE as a petri dish for policy, allowing for all kinds of policy experiments you can't do in the real world. For St. Louis, the team simulated approximately 10,000 policy combinations across 16 different epidemiological scenarios and looked at millions of discreet scenario simulations.

While most other models do meta-analysis based on averages, TRACE goes the other direction, looking at all the possible values and covarying them. This makes for robust results which are critical for policymakers dealing with uncertainty.

"If you want to know how many ER beds you'll need next month, conventional forecasting models are great," Hammond explains. "But if you want to understand all the intervention options across a wide range of scenarios and in a heterogeneous population, these models don't have the completeness of the policy choice set or the uncertainty set. Only by using the complex systems approach," he emphasizes, "can we get these kinds of insights."

Findings point to the value of masks

St. Louis is a big, diverse city that crosses multiple state lines. They face several health challenges — including disparities — and are now grappling with the risk of a fourth wave of COVID-19. For local policymakers, perhaps the biggest takeaway was the importance masks will continue to play in fighting the virus.

The model shows that if you increase the numbers of people wearing masks and wearing them correctly, you can counteract any variants effectively without doing much else. This vital information is now being shared on their health department website.

"Even this far into the pandemic, the scientific literature is unclear about what masks are achieving in the real world," says Hammond. "We were able to show how good you have to assume them to be in order to control the variants."

Lessons learned

For Hammond, the value of working with policymakers has never been more obvious. "Working collaboratively from early in the process to build a model that actually represents their setting and

> MORE ON PAGE 4

The magic behind SFI's Complex Systems Summer School, explained

When warm weather comes, researchers from around the world gather in Santa Fe for an unusual kind of summer school. For four weeks, experts from disciplines ranging from biology to sociology learn the basics of complexity science. Along the way, they learn to think and work in new ways and make life-long connections with other researchers. Participants in the SFI Complex Systems Summer School describe it as "life-changing" and "magical."

> "We wanted to study what happens when you put all these people — biologists, physicists, computer scientists — together."
>
> —JACQUELINE BROWN

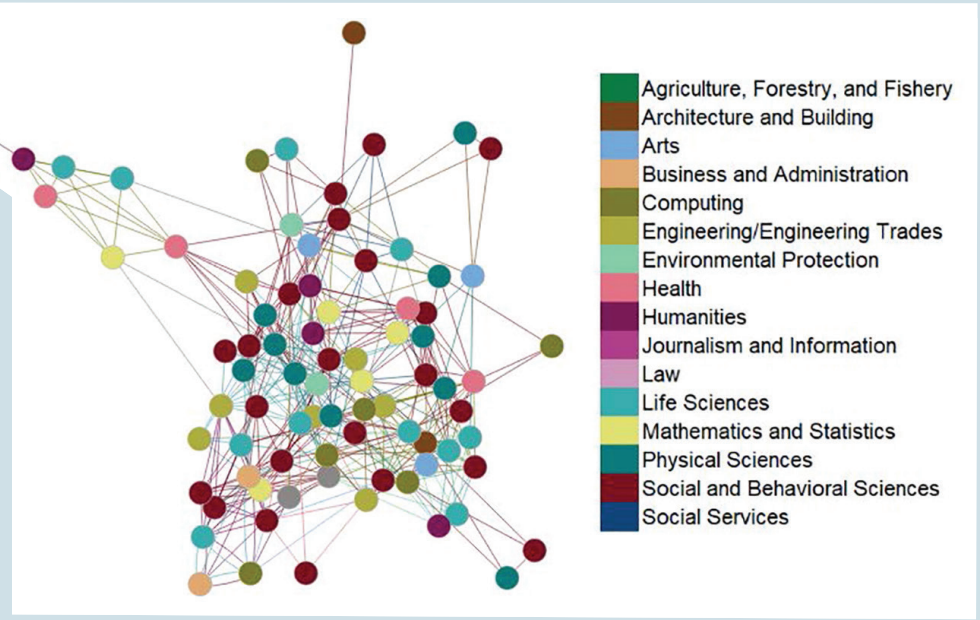
Jacqueline Brown, an urban planning expert at McMaster University, is one of those enthusiastic summer school alums. "It's one of the top academic experiences of my life," she says. "Everyone is so passionate and happy to be there, and there are people coming from around the globe. There are very cool opportunities to collaborate with other people you've dreamed of studying with."

Brown was so moved by her experience there that she and another alum decided to study what makes collaboration at the Complex Systems Summer School so successful. "We were having a really magical experience," says Brown. "We wanted to study what happens when you put all these people — biologists, physicists, computer scientists — together."

The resulting analysis, published in the journal *PLOS One* in February, took a close look at collaboration among a total of 823 participants who attended summer schools from 2005 to 2019. Brown and her team found that the groups were diverse in terms of gender, career position, institution prestige, and country.

"There were no preferences for gender, or people studying at universities at the same level of prestige," Brown says, adding that finding such diversity is unusual in other collaboration studies. "It puts participants on the same playing field. Everyone is a full participant in the project."

But when the team looked at project topics, they found that the social and behavioral sciences were over-represented and that math and engineering were under-represented. They recommended further research to explore what's behind those preferences and how to ensure that project topics are just as diverse as the groups working on them.



Collaboration Network for Santa Fe Complex Systems Summer School 2019. Nodes represent participants and links between nodes indicate collaboration between participants. Both nodes and links are color-coded by academic discipline. (Brown et al, PLOS ONE)

Carrie Cowan, SFI's Director for Education, says she was heartened to see that the school is achieving its goal of creating a collaborative, inspiring culture that attracts people from a variety of backgrounds and professional interests. She hopes SFI can use the findings, along with previous SFI research on collaboration, to further improve the school. "We get a lot of anecdotal evidence that it's successful — people say it's life-changing," says Cowan. "But in addition to that, it's nice to have something quantitative that says, 'this is what's happening.' We'll certainly consider their findings in terms of trying to encourage more multi-disciplinary roots."

LAWS OF THE JUNGLE *(cont. from page 1)*

"What happens when that law for scaling deviates for individual species, or for different contexts? How does that work?" says Kempes. "How do all those fit together?"

The new model extends essential ideas from earlier works for how to set up a model informed by the biological principles of growth, death, and resource competition, but it also allows a user to generalize those ideas to a wide range of species and situations, says Kempes. A user might relax certain assumptions about tree allometries — relationships between size and shape — or incorporate ideas about how trees interact with other organisms, like termites.

By turning these "knobs" on the simulation, Lee says, researchers can more closely reproduce the diverse ways that forests diverge from the idealized model. They can also clearly connect biological principles at the level of the organism to how forest structure plays out on larger scales.

West says the new approach will not only reveal scaling laws that have previously gone unnoticed but also shine a light on new areas of investigation. "One of the great things about having an analytical model of this kind is that it points to where data is missing, or where data is poor," he says, "and the kinds of things people should be measuring."

The model also shows how a physics-inspired approach — which often focuses on idealized situations — can contribute to advances in understanding biological complexity. "There is this marvelous interplay between the fields," West says.

COVID-SAFE SCHOOLS *(cont. from page 1)*

would be amazing — we would be rid of COVID already."

In addition, neither school observed any instance where a teacher was infected by a student or vice versa. While in-school transmission did occur, 72% of those cases in one school were associated with non-mask-wearing. No outbreaks at either school occurred from in-school transmission when mitigation measures were being followed. However, testing revealed a spike in cases at the start of the school year and following fall break — times when the students were out of school — and one school had an outbreak following an out-of-school football party.

So, is it safe to reopen schools, and to do so before all teachers are vaccinated?

"While that depends on your definition of 'safe,' this study says that if you implement all these measures, including testing, there won't be big outbreaks in schools," says Lachmann. "But the key here is testing. If you implement all these measures, testing allows you to see when things go wrong."

Still, there are several caveats. The new, more contagious, variants will likely require schools to be extra vigilant to avoid outbreaks. Also, both schools in this study had the resources to conduct regular testing. "Given that both schools are well-resourced, with a population that likely has a lower burden of chronic disease and better access to medical care, the exact consequence of these introductions in less well-resourced communities is not known," write the authors in the study. "There is a critical need for educational and public health support of rapid expansion of school-based testing capacity and the resources required if communities are to return to in-person education."

COMPLEXITY ECONOMICS *(cont. from page 1)*

recursive algorithms, the researchers developed new models that explored economic problems as they might play out in the messy real world.

Complexity doesn't remedy all the limitations of neoclassical economic theory, Arthur admits, but it can allow for a widening of economic ideas and admit the influence of a greater diversity of forces. And this shift isn't limited to economics: All scientific disciplines are evolving, "embracing openness and process, and asking how structures or phenomena come into being."

PANDEMIC POLICY *(cont. from page 3)*

suits their needs is key," Hammond says. "They then understand and have confidence in the model, and more willingness to act on it."

Once the immediate COVID-19 crisis has passed, Hammond and team will look at lessons learned. "There are real risks of future pandemic events that we have to prepare for," he explains, "but there are also broader lessons about the role of modeling in public policy and its ability to tackle hard problems quickly, and about the way this experience has highlighted disparities for our nation. These models, and the role of a complex systems approach, can be a part of how we address those disparities."

SFI welcomes two new postdocs

MAELL CULLEN

In recent years, games like Chess, Go, DOOM, and Rubik's Cube have provided scientists platforms for studying human learning, cognition, and decision-making. Computational models from these studies illustrate how people move through, and interact with, the games. Incoming Program Postdoctoral Fellow Maell Cullen has used such experiments to model how learning and cognition vary between older and younger brains.

"Now you can simulate unwieldy models with more and more complexity," says Cullen. "But if, midway through, you stop and ask that model 'why did you make that decision,' you can't. They're black boxes."

Cullen, whose research interests include theoretical neuroscience and machine learning, wants to develop better computational models that provide insight into what happens between perception and action — to see the "why" inside that black box.

During his fellowship at SFI, Cullen will be part of SFI's Complex Time — Adaptation, Aging, and the Arrow of Time research theme, working with President David Krakauer, External Professor John Krakauer (Johns Hopkins), and Adrian Haith (Johns Hopkins) to explore the acquisition and loss of skills and cognitive ability, and what characteristics underlie expert-level game performance. His fellowship is supported by James S. McDonnell Foundation 21st Century Science Initiative-Understanding Dynamic and Multi-scale Systems-Collaborative. (DOI# 10.37717/22002049)

Cullen holds a Ph.D. in engineering mathematics from the University of Bristol, an M.Sc. in computational intelligence from Ulster University, and a B.Sc. in neuroscience and smart systems from Keele University.

TYLER MILLHOUSE

The nature of "intelligence" is a tricky thing to pin down, in no small part because it can be defined in so many ways. We're perhaps most familiar with human intelligence and the artificial intelligence of robots. We're learning more about the intelligence of other species, the collective intelligence of animal groups like ant colonies, market intelligence, evolutionary intelligence, and more.

Tyler Millhouse, who began his SFI Program Postdoctoral Fellowship earlier this year, draws on computer science, cognitive science, and philosophy to study a particular aspect of intelligence — how agents, from human scientists to AI systems, model their environments. More broadly, his research "seeks to understand how concepts from AI and machine learning can inform the philosophy of cognitive science and the philosophy of science more generally."

At SFI, Millhouse will work closely with SFI Davis Professor of Complexity Melanie Mitchell and External Professor Melanie Moses to coordinate a series of workshops that will dig into the nuances of the nature, and types, of intelligence. The project, Foundations of Intelligence in Natural and Artificial Systems, is supported by a grant from the National Science Foundation.

Millhouse holds an M.A. in philosophy from Tufts University and a Ph.D., also in philosophy, from the University of Arizona.

ACHIEVEMENTS

On March 15, SFI Resident Artist **Thomas Ashcraft** was featured on NASA's "Astronomy Picture of the Day" website, for capturing video and radio signal recordings of meteors streaking across the night sky. https://apod.nasa.gov/apod/ap210315.html

External Professor **Jessika Trancik**'s 2016 paper on range anxiety and electric vehicles was picked as a five-year favorite by the chief editor of the journal *Nature Energy*.

Nature Communications selected SFI research into information and sociopolitical development for its "Social Sciences Focus" section. Co-authors include SFI's **David Wolpert, Tim Kohler, Jaewon Shin, Michael Price, Hajime Shimao**, and **Brendan Tracey**.

SFI Professor **Sidney Redner**'s paper "Where should you park your car? The 1/2 rule," with co-author Paul Krapivsky, was selected one of the "10 quirkiest physics stories of 2020" by *Physics World*.

The SFI postdoctoral fellows pause for a photo break during Pandemic Pod 2.0.

Postdocs regroup for second 'Pandemic Pod'

Last September, SFI's postdocs launched a cutting-edge experiment. Its objective: to gather a quorum of SFI's postdoc community in one physical place. Its methodology: a combination of stringent COVID-19 testing and 14-day pre-retreat quarantines to ensure that the "Postdoc Pandemic Pod" would remain COVID-free.

Its results? Roaring success.

"I'd 'worked at' SFI for more than half a year, but the retreat was the first experience where I felt, 'I really am at SFI,'" says Jonas Dalege, who arrived as a Program Postdoctoral Fellow in April 2020. Like several Pod-members, Dalege had never met many of his fellow postdocs in person, and the sense of community inspired him to help plan a sequel.

In April, as cases in New Mexico declined and the vaccination campaign was in swing, a second Pandemic Pod ran from April 16–23. Like its predecessor, this second Pod involved strict testing and quarantine measures.

"We continue to play it extremely safe," says Anjali Bhatt, an ASU-SFI Center Fellow who co-organized the first Pod and is running the second alongside Dalege.

Parts of the Pod, such as brainstorm sessions, were designed to mimic SFI's campus life, and its location at a remote, spacious hacienda in the mountains offered even more outdoor workspaces than the Airbnb where Pandemic Pod #1 took place.

Still, Bhatt emphasizes, "the retreat offers a distinct and really additive component that goes beyond what could happen on campus."

"We have held an annual postdoc retreat for many years, but it has become really clear that there has never been a time when it has had as much positive impact," says Hilary Skolnik, SFI's Postdoctoral Fellows Program Manager. "As someone described the last Pandemic Pod retreat, it is 'like SFI on steroids,' generating ideas that "don't surface during a Zoom call."

Says Dalege, "Over the next few months, things are going to be getting back to 'normal' more and more." The Pandemic Pod is certainly part of that movement. "But it will also be a new start."

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RESEARCH BRIEFS *(continued from page 5)*

PERMUTATION ENTROPY

Experimentalists are often tempted to sample their study systems as densely as possible. But for systems where local mixing or diffusion can occur — such as gas within a chamber, chemical mixing within fluids, isotope concentrations within polar ice cores — too-frequent sampling can mask the underlying signal by temporarily shuffling/mixing the observations.

In a paper published in *Physical Review E*, Michael Neuder, a participant in SFI's Undergraduate Complexity Research program, along with SFI External Professor Elizabeth Bradley, SFI Applied Complexity Fellow Joshua Garland, and other coauthors present a solution to this challenge faced by experimentalists from a wide range of fields. "Leveraging the time-delay parameter in the permutation entropy (PE) calculation and studying the resulting relationship between successive PE estimates allows us to identify local mixing scales within the data and identify the maximum frequency for data reporting," explains Garland. "This lets practitioners squeeze every drop of information out of their study system without oversampling — and thereby obfuscating — the signal of interest. Critically, this approach is model-free and requires no prior knowledge of the underlying dynamics or the system being measured."

Read the paper at doi.org/10.1103/PhysRevE.103.022217

IT'S ALIVE? SELF-ASSEMBLED, SELF-BOOTING ARTIFICIAL SYSTEMS

Can life be created in the lab? In the Nature journal *Communications Chemistry*, SFI External Professor Juan Pérez-Mercader and coauthors Chenyu Lin and Sai Krishna Katla in his Harvard laboratory present a new way to design and build self-assembled chemical systems within the lab that mimic simple natural systems. Their polymer vesicles "boot-up" from a soup of inorganic carbon-based molecules and, in an oxygen-rich environment, they follow an evolutionary cycle of growth and implosion.

"The chemistry of a synthetic, micrometer-scale, and out-of-equilibrium artificial system, which by design avoids any biochemistry and uses only 'small' molecules, has the potential to mimic some of life's most fundamental properties," explains Pérez-Mercader. "Life can probably be mimicked within the chemistry lab and, because of it, the universe may even be teaming with it."

Read the paper at doi.org/10.1038/s42004-021-00464-8

SCIENTISTS BRIDGE DISPARATE APPROACHES TO BELIEF DYNAMICS

Why do individuals change some beliefs quickly, but fiercely resist changing other beliefs? On issues like climate change, vaccinations, and genetically modified foods, we're heavily influenced not only by the people around us, but also by the information we receive, our environments, and our individual cognition.

How we form and change our beliefs is a scientific question with profound social implications. It has attracted psychologists, sociologists, physicists, and network scientists — each discipline bringing its own techniques and models. What's lacking, according to SFI Professor Mirta Galesic, is a common framework to unite them.

In a new paper published in the *Journal of the Royal Society Interface*, Galesic and her SFI co-authors Henrik Olsson, Jonas Dalege, Tamara van der Does, and Daniel Stein (also of NYU) outline "a unifying quantitative framework that enables theoretical and empirical comparisons of different belief dynamic models." The framework bridges several divides between current approaches to belief dynamics — most notably, between abstract models that focus on large groups and more finely-grained, individual models of cognitive processes.

Read the paper at doi.org/10.1098/rsif.2020.0857

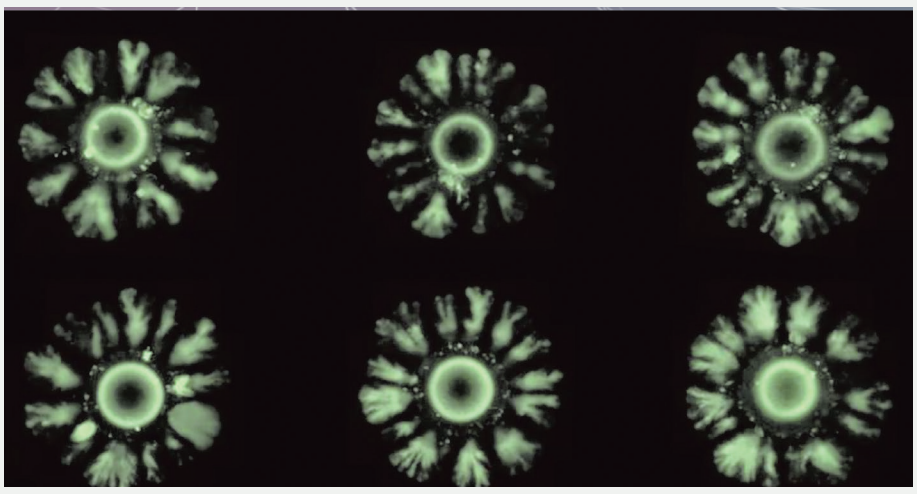
THE NEGLECTED MIDDLE IN POLITICS AND OTHER SPECTRUMS

When people talk about the political spectrum, it's often in reference to "opposite sides." Whether the sides are "conservatives versus liberals," "Republicans versus Democrats," or "left versus right," the center is rarely included — and can be actively excluded, according to Santa Fe Institute research published in the journal *PLOS One*.

In the paper, mathematician Vicky Chuqiao Yang (SFI Omidyar Fellow and Peters Hurst Scholar), sociologist Tamara van der Does (SFI Program Postdoctoral Fellow), and cognitive scientist Henrik Olsson (SFI External Professor) mathematically model how people categorize each other along a spectrum. The foundational hypothesis of their work comes from cognitive psychology and assumes that when people form categories it's to tell each other apart as accurately as possible.

The model predicted that when two groups form, both want to exclude those in the middle — a dynamic born out by a large dataset from U.S. political surveys. The main takeaway of this work is that the middle falls through the cracks of the categorization process — and not just in politics. The researchers' model could also be applied to understand how social categories form around other attributes, like skin color.

Read the paper at doi.org/10.1371/journal.pone.0247562



Petri dish with engineered E. coli forming Turing patterns (Photo: Ricard Solé)

CREATING TURING PATTERNS IN THE LAB

Just before computer science pioneer Alan Turing's untimely death in 1954, he devised a theory that continues to intrigue scientists more than half a century later. It mathematically answers the riddle of how complex, regular patterns — like the spots on a leopard or the stripes on a seashell — can arise from a simple, homogeneous system.

A new study led by SFI External Professor Ricard Solé, published February 19 in the journal Synthetic Biology, based at Universitat Pompeu Fabra and Salva Duran-Nebreda of the Institut de Biologia Evolutiva in Barcelona shows how a new class of Turing patterns work, using synthetic biology to create them from scratch in the lab.

The framework, which grew out of a collaboration between Solé and Duran-Nebreda at the Santa Fe Institute, can be applied to the study of other biological systems, such as social insects.

Read the paper at doi.org/10.1021/acssynbio.0c00318