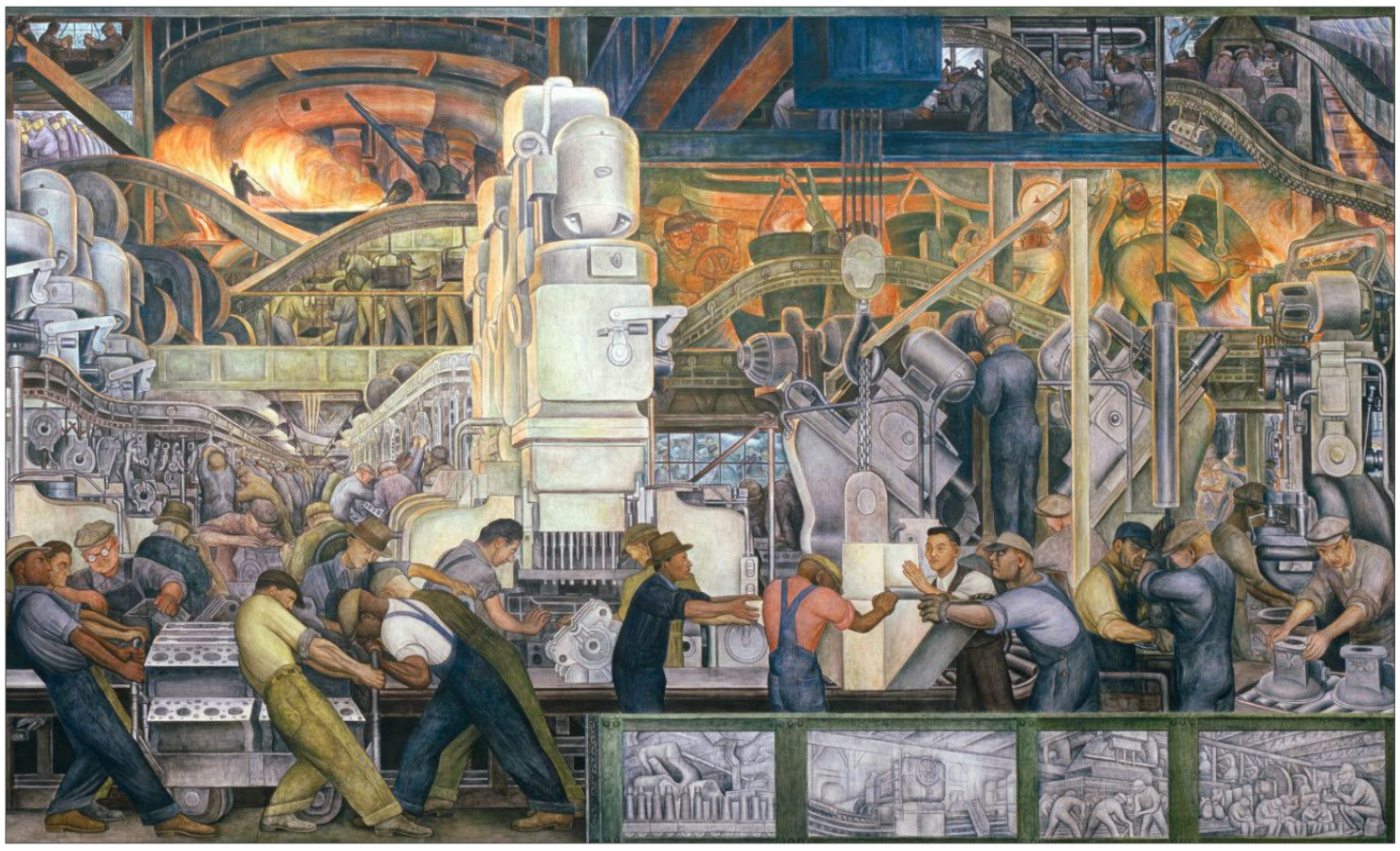
SPRING 2022

Parallax

THE NEWSLETTER OF THE SANTA FE INSTITUTE



From Detroit Industry, North Wall, 1932-33, fresco by Diego Rivera. Detroit Institute of Arts. (Image: Detroit Institute of Arts)

Omidyar grant funds new research theme

The Santa Fe Institute has received funding for a new five-year research theme on emergent political economies. The theme, funded by a $6.5 million grant from the Omidyar Network, will take up the ethical imperative to develop better theoretical frameworks and methods to understand the social, ecological, and material inequalities at the core of the modern economy, as well as imagine the role that innovation will play in emergent political economies of the future-both for good and ill.

In the eighteenth century, Adam Smith conceived of capitalism in response to poverty. "Free market theory was an ethical matter, and Smith theorized that the free market would help solve the social ills that mercantilism generated," explains SFI President David Krakauer. "What he did not anticipate, however — what he could not have anticipated given his toolkit — was that capitalism plus technology, under many conditions, can generate externalities that exceed the political-economic damage of mercantilism — from unemployment to climate change. Adam Smith needs to meet complexity economics."

If the contemporary global economy has made anything clear, it is that the political and theoretical methods and tools that researchers have inherited are insufficient to deal with the emergent patterns, systems, and phenomena that shape global economic life.

SFI's Omidyar-funded research network will be one of five research centers, each focused on the renewal of political and economic thinking in theory and policy. The four fellow centers, all supported by the William and Flora Hewlett Foundation, are housed at Harvard's Kennedy School, Howard University, the Massachusetts Institute of Technology, and Johns Hopkins University. The total funding for the network of institutions is $41 million.

In the SFI network, research will be conducted through a series of working groups and workshops and will home in on different emergent properties of economic complexity. One of the first workshops, led by SFI External Professor Ricardo Hausmann, is called "The Study of Technology." The group will theorize the structure of technology and develop better mathematical frameworks that capture how technology — in all of its diversity — evolves.

Hausmann explains the challenge this way: "Formalizing ideas about technology has always

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Can algorithms bend toward justice?

Increasingly, algorithms rule our world. They guide doctors toward our medical treatments, advise bankers on whether to give us a home loan, help judges decide whether to release us on bail. They're often hidden and mysterious, guiding our lives in ways we don't understand. Are they doing a good job? In particular, are they fair, or are they treating some groups of people better than others?

In March, SFI brought together experts from a range of disciplines, including computer science, law, philosophy, and the social sciences to discuss the following question: Can algorithms bend the arc toward justice? The workshop was organized by SFI External Professors Melanie Moses (University of New Mexico) and Tina Eliassi-Rad (Northeastern University) and UNM Law Professor Sonia Gipson Rankin, who are all members of the SFI & UNM Interdisciplinary Working Group on Algorithmic Justice. The workshop, part of a series on the foundations of natural and artificial intelligence, is part of an NSF Artificial Intelligence Research Institute planning grant led by SFI's Davis Professor of Complexity Melanie Mitchell and Melanie Moses.

To begin, the group analyzed the notion of justice itself, which tends to be understood very differently by computer scientists, ethicists, and lawyers. Computer scientists tend to have a narrow but precisely defined view of fairness — a view that is useful for writing or analyzing algorithms, but often too utilitarian to capture what social scientists, philosophers, lawyers, and everyday people mean by "justice." One challenge is to find practical ways of deepening algorithmic justice to incorporate broader definitions.

Working group participants also discussed the regulations or incentives needed to ensure that algorithms are working in our best interest; they developed a comprehensive theory

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Workshops explore individual and collective intelligence

Are ants intelligent? Watching an individual ant carry a bit of leaf back to the anthill, it may not seem that way, but as a group, the colony exhibits a kind of collective intelligence, says SFI's Melanie Mitchell.

"If you look at the ant colony, each individual ant is not very intelligent and can't do much on its own, but working together, the hundreds of thousands of different ants in a colony can do all kinds of seemingly intelligent things, like building elaborate structures underground that regulate temperature and humidity," says Mitchell, the Davis Professor of Complexity at SFI, who conducts research on visual recognition and conceptual abstraction in AI systems.

Insects' collective intelligence was just one of the topics of a workshop Mitchell co-organized and participated in last August. The gathering, held virtually due to the pandemic, pooled knowledge from biologists, computer scientists, and other experts to further the conversation about collective intelligence research and how it can inform AI. Some of the questions the group explored were: What mechanisms allow collective intelligence to emerge from a group of individuals or components? Which AI research paths hold the most promise for solving complex collective problems like climate change or epidemics? How can we harness collaborative intelligence to increase fairness and other key values?

Highlights of the workshop, part of SFI's Foundations of Intelligence project, included a talk by Jeff Hawkins, co-founder of the AI organization Numenta, on how communication between columns of neurons in the brain is a form of collective intelligence, a discussion on resolving semantic ambiguities that hindered learning across fields, a debate about how to improve the study of democracy, and a discussion on the spread of misinformation.

"One of the things I took away from several of the talks was the need to tune individual agents and the conditions under which they interact in order to enhance their collective intelligence," says SFI postdoctoral fellow Tyler Millhouse, who also helped organize the

Ant bridge collective (photo: Shutterstock)

workshop along with SFI External Professor Melanie Moses. For example, biologist Anna Dornhaus noted in her talk that in insect colonies, more information-sharing between

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BEYOND BORDERS

EMERGENT POLITICAL ECONOMIES & A SCIENCE OF POSSIBILITY

"All actions, and all things indeed, are good or bad by relation only. Nothing is so complex as relations when considered with regard to a society, and nothing is so difficult as to discover truth, when involved and blended with these relations."

JAMES STEUART, *An Inquiry into the Principles of Political Economy*, Chapter 1 (1767)

James Steuart's *Inquiry Into the Principles of Political Economy* — a founding monograph in the field — manages to capture many of the challenges that modern political and economic public dialogue seem to have lost — notably an appreciation for the inherent complexity of relational systems whose core — and perhaps even axiomatic — rules are ethical principles. As Steuart writes in relation to changing such a system in order to improve the collective conditions for life, "The great art of governing is to divest oneself of prejudices and attachments to particular opinions, particular classes, and above all to particular persons; to consult the spirit of the people, to give way to it in appearance, and in so doing to give it a turn capable of inspiring those sentiments which may induce them to relish the change, which an alteration of circumstances has rendered necessary."

For Steuart the objective of society — that is, any social collective in which the parts become correlated towards synergistic positive outcomes — is to build a political economy that can "provide food, other necessaries, and employment to every one of the society." The path Steuart favored was a mild mercantilism, a position that his more famous, and in several ways more enlightened successor, Adam Smith, made the just target of his criticism.

In *An Inquiry into the Nature and Causes of the Wealth of Nations* (1776), Smith introduces a language that is more consonant with our own, placing a greater emphasis on technology and industry and reducing the focus on tax and trade favored by Steuart. Smith can often sound like a Pollyanna of the modern techno-savant variety: "It is the great multiplication of the productions of all the different arts, in consequence of the division of labor, which occasions, in a well-governed society, that universal opulence which extends itself to the lowest ranks of the people." Smith, however, fully recognized the human cost of excessive specialization and mechanization. He possessed a very sophisticated sense of human potential and ability, and advocated for extensive educational opportunities for all:

"The difference of natural talents in different men, is, in reality, much less than we are aware of; and the very different genius which appears to distinguish men of different professions, when grown up to maturity, is not upon many occasions so much the cause, as the effect of the division of labor. The difference between the most dissimilar characters, between a philosopher and a common street porter, for example, seems to arise not so much from nature, as from habit, custom, and education."

Much of *Wealth of Nations* is dedicated to an analysis of the constraints and costs of technology, industry, and their respective markets as they bear on what Steuart described as the complexity of human relations. For Smith,

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Parallax is published quarterly by the Santa Fe Institute. Please send comments or questions to Katherine Mast at katie@santafe.edu.

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SFI IN THE MEDIA

In March, T*he American Prospect* highlighted **Geoffrey West**'s work on city scaling in a story about rural American economies.

Insider featured work by **Mahzarin Banaji** from 1995 that paved the way to a better understanding of implicit bias.

In a news feature about how researchers are working to increase fairness in citations, *Nature* spoke with **Dani Bassett** about racial and gender bias in rates of citation.

Throughout the past quarter, **Lauren Ancel Meyers** and **Sam Scarpino** have individually discussed various aspects of the COVID-19 pandemic with multiple outlets, from the *Financial Times*, NPR, and the *New York Times* to *The Washington Post*, CNN, and Colorado Public Radio. In March, Scarpino spoke with the *Guardian* about COVID-19's BA.2 surge in Europe and what that might portend for the U.S., and Meyers told *The Atlantic* why good data, and time, are important for making predictions about how BA.2 will play out.

Science News covered **Mingzhen Lu's** research on the ecosystems maintained by the world's thinnest roots (see below).

The Gothamist spoke with **Tim Kohler** about the latest UN climate change report and its implications for New York City and other coastal communities.

After a 16-year hiatus, **Cormac McCarthy** has two novels slated for publication this fall. *The New York Times* discussed the upcoming titles, "The Passenger," and "Stella Maris," while the LA *Review of Books* looked back on "Blood Meridian," published nearly 40 years ago.

Fast Company turned to work by **Melanie Mitchell** as it explored three reasons we still drive manned cars.

Fast Company also spoke with **Josh Wolfe** about the threat of Russian cyberwar, and how the U.S. and others might threaten the same, preemptively. Wolfe also discussed his investment strategies in a Q&A with CNBC.

Doyne Farmer spoke with *The New Yorker* about a forthcoming report on why a decisive shift to renewable energy makes good financial sense.

In a February opinion piece about President Biden's plans to nominate a Black woman to the Supreme Court, *The Hill* cited **Scott Page** and Lu Hong's work showing that diversity is important for groups tasked with solving problems.

"We came up with a way to measure the intelligence of entire planets," wrote **Sara Walker** and coauthors in an essay for *The Atlantic*. "Things aren't looking great for ours."

Ricardo Hausmann wrote an op-ed in *Project Syndicate* discussing why a punitive tax on Russian oil would be more credible and sustainable than an embargo.

SFI's local alt-weekly, the *Santa Fe Reporter*, interviewed **David Krakauer** for an in-depth review of the newest book from the SFI Press, *The Complex Alternative*.

Writer Marco Bruna took readers of the Italian daily *Corriere della Sera* on a tour of Santa Fe and of SFI through the eyes and words of **David Krakauer**, **Cormac McCarthy**, and **Sam Shepard**.

World's thinnest roots drive landscape pattern

We typically think of plants strutting their best stuff aboveground: showy flowers, fragrant blossoms, and unique shapes abound. But their development below ground is equally magical.

"For the last 400 million years, since plants colonized land, roots have been the true engine of terrestrial nutrient cycling," marvels SFI Postdoctoral Fellow Mingzhen Lu, the lead author of a new study in the *Proceedings of the National Academy of Sciences*. "Roots are the foundation of biodiversity."

Lu and his team of international collaborators, which included William Bond (University of Cape Town) and Lars Hedin (Princeton University), dug deep to better understand one of the most extraordinary root systems in the world.

The researchers conducted a four-year experiment to explore the stark divide between the Fynbos and Afrotemperate Forest biomes in South Africa's western cape. Fynbos, a shrubby biome with tremendous plant diversity, abuts Afrotemperate Forest, a woodland dominated by a small number of tree species. The unusual biome boundary is so narrow that within a few steps, one passes from a hot, open shrubland into the cool, mossy shade of the forest.

The sharp delineation is made even more distinct because the two biomes share an underlying geology and are subject to the same climatic patterns — they exist as alternative stable states. In the face of extreme disturbance, the biomes could potentially shift to reflect the neighboring plant communities.

"Some systems can exist in different states — like water and ice," explains Hedin. "This makes them especially interesting as models for dramatic change because they can switch from one state to another, which is especially urgent in a world being stressed by climate change."

Fynbos endemic species Leucadendron strobilinum *on Table mountain, Cape Town. (Photo: Mingzhen Lu.)*

Under this backdrop, the study revealed two significant findings. First,the two biomes exhibited marked differences in their root traits. Second, these root differences allow the Fynbos plant community to deter trees by limiting below-ground nutrient availability. Specifically, Fynbos plants rebuff invasion with the thinnest roots ever identified.

"We found that across the world's ecosystems, these roots are the thinnest of all," says Lu. "For every 1 gram of carbon — the weight of a paperclip — these plants produce roots 15 football fields long."

The stringy roots allow Fynbos species to outcompete thicker-rooted plants in nutrient-poor soils.

"The thin roots of Fynbos are the below-ground weapon creating miserable conditions for nutrient-demanding forest plants," says Bond. "We now see that it is not the intrinsic soil properties, but plant feedbacks to the soil, that create misery for forest saplings."

Compounding the "nutritional misery," as the authors describe it, the Fynbos biome is prone to frequent, hot fires that combust accumulated

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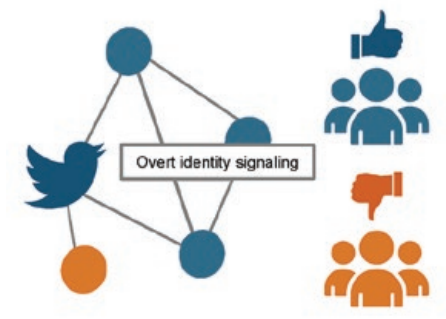
Subtle signals convey meaning in online forums

A new paper in the *Proceedings of the National Academy of Sciences* demonstrates empirically for the first time that people use covert signals of their political identity online. The signals are subtle messages that convey meaning to other in-group members and mean little to anyone else, allowing people to communicate with others who share their political identity without risking pile-ons from those who disagree. The study also found that people use covert signaling more often in mixed groups, preferring obvious, overt signals in groups that mostly share their beliefs.

These ideas were developed in a theory of covert signaling by Paul Smaldino, associate professor of cognitive and information sciences at UC Merced, but had yet to be tested. "This is very hard to study empirically," says Tamara van der Does, a postdoctoral fellow at SFI and lead author of the paper. "How do you measure a covert identity signal, given that it's covert?"

She and her coauthors, including SFI Professor Mirta Galesic, puzzled over the question for months until they came up with a clever strategy. During the run-up to the 2020 election, they collected tweets from politically extreme Twitter users, on both the left and the right. Indiana University graduate student Zackary Dunivin developed a method to download follower networks and determine if the followers were mostly similarly extreme, or more heterogeneous. Then for each tweet, they had four groups of raters guess the political affiliation of the tweeter. Some of the raters were politically extreme, either on the right or the left, and some were more moderate. The tweets that generated the most disparate guesses between these groups were selected as the most likely to be covert signals.



Twitter users are more likely to overtly share their political opinions when in groups of people who think similarly, and tend to use covert signals when in mixed groups . (Illustration courtesy the authors)

Finally, the raters played an online game, where they selected from overt and covert tweets to share with groups of audience members who were either strictly politically co-partisan with the rater or mixed co- and cross-partisan. Their goal was to maximize likes and avoid dislikes from the audience members.

"We wanted to see: when there are more audience members from the out-group, do participants in the game share more covert tweets?" van der Does says. "We were quite mind blown in that it was actually the case!"

This research was supported by the Army Research Office Grant #W911NF2010220.

Flocks of birds overwintering at Bosque del Apache National Wildlife Refuge display collective behavior as they fly in and out of feeding areas at dawn and dusk. (Photo: Katherine Mast)

Constructing and deconstructing collectives

Fireflies do it, ants do it, microbes do it — and humans do it, too: we all form collectives. We come together in groups, behaving in ways that are shaped by complex systems of patterns and interactions. We also break apart. Figuring out how that happens can help us understand our responses to some of the world's biggest challenges.

"I think the problem of collectives is the most important problem of our society today — to understand what are we doing, where are we going, how can we maybe tweak our systems to function better in these new technological and political circumstances," says SFI Professor Mirta Galesic.

She and colleagues Michael Hochberg (SFI External Professor, University of Montpellier) and Jeremy Van Cleve (former SFI Postdoctoral Fellow, University of Kentucky) organized a recent three-day meeting on collective behavior.

"Constructing and Deconstructing Collectives: Signals to Space and Society," a virtual workshop in late December 2021, drew 45 scientists from physics, anthropology, psychology, evolutionary biology, and beyond. "We are building our own collective," Galesic says, to explore new research directions in collective behavior.

The past two years of the pandemic provided a real-life lab for some of their questions. "COVID-19 was a great example," Van Cleve says. "We continually see certain patterns, increasing division, people sort of breaking apart into factions that are aligning in kind of completely predictable ways." Understanding those behaviors could offer insights into human groups and their responses to pressing problems — whether it's a public health threat or environmental change.

These studies lead to questions about "individual freedom versus what's best for the collective," Hochberg says. Ultimately, we all hope to know: "How do we get greater degrees of alignment on important issues?"

Collective behavior happens all around us. Male fireflies synchronize their flashing to what others nearby are doing. Army ants build living bridges across gaps in the forest floor. Researchers hope to build mathematical models that explain such behaviors in other organisms to better understand human collectives. "That was really a unifying thread," Galesic says.

These are big questions, and "we're just scratching the surface," Hochberg says. Stay tuned — the collective has more research and discussion to come.

Science of science workshop: discovery and inequality

In the late 1800s, a collection of sociologists and philosophers started to try and make sense of the steady yet chaotic progress of scientific discovery, which physicist Freeman Dyson has referred to as "a succession of illogical jumps, improbable coincidences, jokes of nature."

The "science of science," as the endeavor is now known, turns the scientific method inward, on the scientific ecosystem itself, to understand its structure and dynamics. Largely confined to sociology and philosophy for decades, advances in computer technology at the turn of the century broadened the discipline into what is now an interdisciplinary field encompassing computer scientists, statisticians, biologists, physicists, and more.

Today's collaborative and diverse research community reflects SFI's mission. This May 5-6, the Institute will host a meeting called "A New Synthesis for the Science of Science." Postponed three times by the COVID-19 pandemic, the workshop will synthesize concepts, models, methods, and data to craft a new vision for the science of science.

"The data and computational tools available today are transforming the field," says SFI External Professor Aaron Clauset (University of Colorado Boulder). "This workshop aims to articulate the organizing questions that should guide the next five to 10 years of work."

In addition to Clauset, workshop organizers include SFI Professor Mirta Galesic and former SFI Postdoctoral Fellow Daniel B. Larremore, Assistant Professor of Computer Science at the University of Colorado Boulder.

The workshop will focus on the individual and structural inequalities within science that slow the pace and limit the diversity of discovery. Specifically, participants will explore the mechanisms that produce epistemic and social inequality, the removal of which would accelerate and broaden scientific advances.

> . . . why do a handful of graduate programs produce 50 percent of all tenure-track faculty across different fields? Or why do women produce fewer papers throughout their careers than their male peers?

For example, why do a handful of graduate programs produce 50 percent of all tenure-track faculty across different fields? Or why do women produce fewer papers throughout their careers than their male peers?

These questions are even more timely and pertinent after the global pandemic disrupted all levels of science. "The pandemic has inflamed epistemic inequalities, particularly around women," says Clauset. "The workshop will help us address the underlying causes of pervasive inequalities in science."

Adds Galesic, "This research can help us to see how some deeper changes in the system can alleviate structural barriers and inequalities."

This meeting was supported by the National Science Foundation Grant Number 2006355.

Using organization to counter online hate speech

Hate speech and disinformation have become intractable problems on social media and other online platforms, but there is little agreement on what to do about them. One approach is for companies to monitor and remove hateful or harmful content. Another emerging approach is counter speech, where individual users respond to bullying posts.

But is counter speech effective at curbing online hate and disinformation? It's a difficult question to address scientifically because so many societal factors are at play beyond the online forums. However, a study published in *EPJ Data Science* uses a multifaceted approach to begin exploring the question. The study examines four years' worth of conversations that played out on German Twitter between two self-identified, opposing groups. The results suggest that counter speech may indeed be effective in curbing hateful speech online, especially when done in an organized manner.

> "This is the first time anyone has done a longitudinal study of complete conversations at this scale," says Garland.

Shortly before the 2017 German federal election, a far-right group called *Reconquista Germanica* began to organize targeted online campaigns, spreading hate and disinformation against immigrants through various social media platforms and promoting a radical-right political party. In April 2018, a counter group called *Reconquista Internet* organized coordinated counter-messaging.

In their paper, "Impact and dynamics of hate and counter speech online," former Applied Complexity Fellow Joshua Garland and SFI Professor Mirta Galesic, along with former SFI Postdoctoral Fellows Keyan Ghazi-Zahedi (Max Planck Institute for Mathematics in the Sciences), and Laurent Hébert-Dufresne (University of Vermont), and Jean-Gabriel Young (University of Vermont) studied more than 180,000 conversations from 2015 — before the formation of *Reconquista Germanica* — through 2018.

"This is the first time anyone has done a longitudinal study of complete conversations at this scale," says Garland. "We were able to collect these conversations and then to study the dynamics between the two groups."

Because there were self-identified members of both groups, the team was able to train a machine learning classifier to recognize speech patterns typical of hate and counter speech in the conversations.

To get a picture of the effectiveness of counter speech, the authors considered several proxies for effectiveness at multiple scales, from the overall ratios of hate-to-counter speech over time to the dynamics of individual hate and counter-speech posts.

"Across a number of different indicators, we find that organized counter speech appears to contribute to a more balanced public discourse. After the emergence of the organized counter group *Reconquista Internet* (RI) in the late Spring of 2018, the relative frequency of counter speech increased while that of hate speech decreased," write the authors.

Similar to what research on "traditional" bullying shows, these findings suggest that the presence of supporting peers can motivate individuals to stand up against online hate speech. "Our work suggests it is important to encourage citizens to stand together against hate and bullying online," says Galesic. "They will feel empowered, and they can really make a difference."

The authors are careful to clarify that their study does not identify any causal effects. "There were simultaneous cultural shifts happening in

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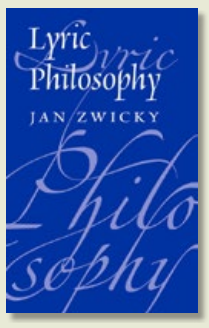
What we're reading

Books chosen by SFI scholars on the theme of 'amplitude'

In an essay called "The Storyteller," Walter Benjamin uses the term "amplitude" to describe creations that cannot be exhausted by interpretation or analysis. Writing in the 1930s, Benjamin was frightened by how the overflow of information and technology was impoverishing our ability to share experience in meaningful ways. According to his view, literature with amplitude supports a vast range of understandings depending upon the disposition of the reader and the context or mood in which the work is received.

Works high in amplitude allow readers to plumb their own depths without generating meaningless verdicts, "and the story thus acquires a breadth that information lacks." At a time when conviction rather than curiosity was the dominant socio-political attitude, Benjamin believed humans could still convene around the compressed wonders that provoke marvel.

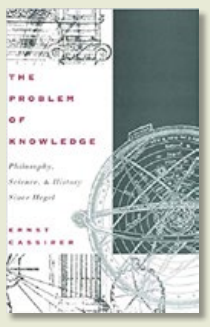
Our theme for this installment of "What We're Reading" is amplitude in this aesthetic sense: breadth beyond the limits of mere data. Each in its own way, the three books listed here recognize and foster the amplitude inherent to the ongoing "storytelling" of art, philosophy, science, and the cosmos we inhabit.



SIENNA LATHAM,
Managing Editor,
SFI Press

***Lyric Philosophy*, by Jan Zwicky**

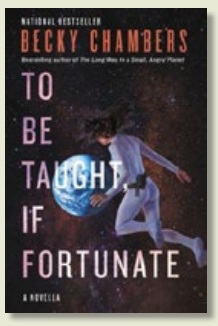
Zwicky is perhaps my favorite living philosopher because she echoes and embodies the Wittgensteinian conviction that philosophy also resides outside the boundaries set by the discipline — sometimes the unsayable can still be showable. This 1992 work pairs Zwicky's aphorisms with a chorus of perspectives spanning the poetic, musical, and scientific in a focused exercise in resonance.



MANFRED LAUBICHLER,
SFI External Professor
(Arizona State University)

***The Problem of Knowledge: Philosophy, Science, and History Since Hegel*, by Ernst Cassirer**

This masterpiece sketches the development of how we came to know and understand the world through a number of interconnected epistemic lenses. It is hard to imagine that anyone today would be able to acquire both the breadth and depth of knowledge to produce such a synthesis. Of particular note is the section on the development of ideas about life (leading to what we now call biology). This section ends in the 1930s. Here is a challenge: can we combine forces to write with similar clarity about the next 100 years?



CRIS MOORE,
SFI Professor, Science Board Member

***To Be Taught, if Fortunate*, by Becky Chambers**

Life is both profuse and tragically finite. Filled with beauty, dignity, heartbreak, and a strange hope, this gem of a novella will renew your sense of wonder and your faith that science is a form of service to the universe.

Community lecture series re-emerges

Since 1987, the Santa Fe Institute's Community Lecture Series has shared complexity science with an enthusiastic local audience. The COVID-19 pandemic forced the series to pause in March of 2020. Two years later, the series returned to its local home at the Lensic Performing Arts Center on March 22, 2022, with a talk by SFI External Professor Sara Walker, an astrobiologist at Arizona State University. In her community talk "Recognizing the Alien in Us," Walker expanded on themes that were introduced in SFI's first Community Lectures more than three decades ago.

"We've recorded and streamed our lectures for years now, and we committed to producing rich virtual complexity content throughout the pandemic, but the reprisal of this lecture series, in person, in Santa Fe, is more than a symbolic return to our roots," says SFI Miller Omega Programs Manager Caitlin McShea, who facilitates the event. "When the series 'went dark,' the science revved up, and it's exciting to share this research with the people in our community who weathered the storm alongside us. The brilliant thing about the lecture series is that it is utterly accessible."

The range of topics — from quarks to food webs, cultural evolution to urban scaling laws, and emergent economics to Gaia — covers many of the most profound ideas of the 21st century.

The inaugural lectures in 1987 — "Order from Chaos: Different Ways of Thinking about the Origin of Life," presented by Stuart Kauffman, one of SFI's first resident researchers, and "The Zen of Biology: Life Sciences in the Computer Age," presented by the late George Mason University biophysicist and SFI Science Board Chair Emeritus Harold Morowitz — set the pace for the lectures that would follow. A new electronic archive documents the series from its inception. The range of topics — from quarks to food webs, cultural evolution to urban scaling laws, and emergent economics to Gaia — covers many of the most profound ideas of the 21st century.

The SFI Community Lecture series full lineup for the year. (Image: SFI)

"We began the series with two lectures that explore biophysics and the origin of life, and we re-emerge, after two years, with a lecture that shows how this fascinating subfield of complexity science has evolved," says McShea. "It's a nice bit of serendipity."

The lecture series is free and open to the public, thanks to generous support from longtime SFI supporters and local philanthropists Ian and Sonnet McKinnon, but reservations are required and the event is often filled to capacity. To reserve a ticket, visit www.lensic.org. The lectures are also live-streamed, and made available after the event, on SFI's YouTube channel.

POLITICAL ECONOMIES *(cont. from page 1)*

been made difficult by the challenges of defining technology, and by the immense diversity of the things we call technologies. What mathematics would be as suited for bicycles as for horticultural grafting, DNA sequencing and HTML, water wheels and Gore-Tex, the Bessemer process and agile project management?"

The SFI network will also present generative exchanges between SFI scientists and thinkers who are exploring new conceptions of the economic landscape and recovering ideas that help us understand our inherited systems. In the coming year, SFI's Complexity podcast will offer a series of episodes that pair innovative thinkers — political theorists, fiction writers, futurists, and economic historians — with SFI scientists and the show's host, Michael Garfield.

"We're going to be creating a trialogue," says Garfield, "that gives us a more stereoscopic view on topics in emergent political economy that range from urbanization, to banking credit cycles, to immigration, to the ways that speculative fiction might help us imagine possible economic futures."

In order to bring complexity economics to a broader global context, SFI is hiring a new Diversity and Complexity Fellow who will lead SFI's diversity research and outreach initiative. The Fellow will be charged with developing quantitative techniques to identify scholars and communities engaging with complexity-oriented thinking in under-represented communities and institutions, and will work to introduce complexity science to historically underrepresented scholarly communities.

On a cross-institutional scale, Krakauer hopes that SFI's network will inspire researchers across institutions to collaborate and engage with complexity economics. "It's much like the early days of the human genome project," Krakauer says, "the spirit of competition and cooperation between institutions will help us illuminate the elements of a complex system that is far greater than the sum of its parts."

Ultimately, SFI's research network and the significant network of fellow institutions together are poised to generate the kind of thinking and theory that will capture the emergent dynamics of a global economic system that we are only beginning to understand.

ALGORITHMIC JUSTICE *(cont. from page 1)*

that would lead algorithms to be more robust and adaptive; and they looked for ways that algorithms could be designed with feedback loops that would break down existing biases rather than reinforce them.

"What I think is unique about SFI," Moses says, "is the ability to bring together scholars from different disciplines to have a productive discussion. We learn from one another and chart a path forward where artificial intelligence advances justice rather than exacerbates or accelerates injustices."

INTELLIGENCE *(cont. from page 1)*

individuals isn't necessarily beneficial to the colony as a whole. "These biologically-inspired ideas illustrate an area for improving collective AI that might not have been obvious otherwise."

This workshop was part of the ongoing Foundations of Intelligence project, which has included Foundations of Intelligence in Natural and Artificial Systems (March 15-19, 2021), Frontiers of Evolutionary Computation (July 21-23, 2021), Can Algorithms Bend the Arc Toward Justice? (March 30-1, 2022), and Embodied, Situated, and Grounded Intelligence: Implications for AI (April 12-15, 2022).

FYNBOS ROOTS *(cont. from page 2)*

nutrients in the soil. The nutrient-hoarding below-ground strategy combined with a collective fire-adaptation allows the Fynbos plant community to favor its own persistence by modifying its environment. On the other side of the biome divide, the forest is doing the same thing.

The findings suggest that alternative stable states can be maintained through biotic mechanisms, such as root traits, in addition to the commonly understood abiotic factors like climate. This insight is critical to conserving threatened ecosystems around the world.

"It is profound to see microscale plant traits, like root thickness, linked to macroscale emergent ecosystem patterns," says Lu.

"Who would have thought it was the roots that help explain this bi-stability?" asks Hedin. "It blows my mind."

HATE SPEECH *(cont. from page 3)*

Germany," says Garland. "We can't say that organized counter speech caused something to occur, but we can look at the correlation between hate and counter speech."

While this study focuses on the specific scenario of hate and counter speech on German Twitter, the findings offer insight for addressing other types of online disinformation. "Hateful messaging is really a subset of disinformation," says Garland. "It's disinformation about a person or group of people. Our paper shows that organizing matters to fight against disinformation. It might be scary to stand up against a neo-Nazi on my own, but if I can use a hashtag or post on a platform where I have support, it's easier to stand up against the bully."

In subsequent work, the authors plan to explore which specific strategies — from humor to counterfactuals to befriending — might be the most effective types of counter speech.

BEYOND BORDERS *(cont. from page 2)*

the enterprise of political economy was the betterment of society as a whole, and while an unabashed advocate for free markets, advanced technology, and capitalism, he concluded his book by writing, "The expense of maintaining good roads and communications is, no doubt, beneficial to the whole society, and may, therefore, without any injustice, be defrayed by the general contributions of the whole society." And "The expense of the institutions for education and religious instruction, is likewise, no doubt, beneficial to the whole society, and may, therefore, without injustice, be defrayed by the general contribution of the whole society." Smith was able to hold what might strike many today as contrary opinions. He was, in other words, capable of complexity.

Along with our various partnering institutions, the Omidyar Network-supported theme at SFI on emergent political economies seeks to restore to our current historical moment the awareness of the complexity, trade-offs, and ultimate ethical objectives that were so clearly present and set out at length at the scholarly inception of this field. To grapple with the obvious fact that "Nothing is so complex as relations when considered with regard to a society."

In our own time, issues relating to the uncertainty of work associated with growing mechanization, our awareness of the obvious ecological, geochemical, and global climate impacts of industry, the highly heterogeneous access of the growing planetary population to food, education, and employment, and problems of sustainable agriculture, add vastly scaled-up challenges to those discussed in the 18th and 19th centuries. These are not controversial observations. Yet they have generated divided scholarship and beliefs.

At SFI we think that complexity economics, and a variety of new models and theories that have grown out of the study of the complex domain — when added to the mix of modern economic theory and political science — will enrich and integrate this discussion. In time we hope to inform others with greater practical experience and wisdom to consider pluralistic ways of bringing these ideas to bear on novel policies in both private business and government. There has never been a doubt in my mind that most of us, in Smith's words, seek practices "beneficial to the whole society." It is, however, certainly the case that we have barely scraped the surface of what those practices might look like when taking into account all that we have learned in the last several decades.

— David Krakauer
President, Santa Fe Institute

In a time of upheaval, what does it mean to be useful?

In a time of climate change, inequality, polarization, and pandemic, what does it mean to be "useful?" This question from SFI President David Krakauer kicked off SFI's live online course Complexity Interactive, which ran January 10-28, 2022. Is it better for complex systems scientists to keep their advice simple and be understood, or to advocate for complexity and nuance yet risk that no one will listen?

This year's Complexity Interactive focused broadly on sustainability. Participants represented six continents and 28 countries, with interests as different as space weather, regenerative agriculture, and comparative theology. The curriculum gave participants an overview of current research at SFI, engaged them in transdisciplinary thinking with colleagues, and inspired ideas and approaches for future research using the tools of complexity science.

A series of seminars and discussions throughout the three-week program uncovered how complexity theory can reveal patterns and explanations across a variety of systems, and explored how complex-systems approaches could inform solutions to global challenges.

SFI Professor Geoffrey West used his work on scaling theory to explain why people die but cities don't, and why the unbounded growth of cities may not be good news. "Everything comes at a price. This does, too," said West. "The theory tells you what's going to happen if you do insist on continuing. It tells you: you collapse." Other talks focused on how innovation, including parallels between technological invention and biological evolution, might prevent collapse.

SFI External Professors Brian Enquist (University of Arizona) and Mary O'Connor (University of British Columbia) explained how humans and climate change affect ecosystems. Across the world, species diversity — biodiversity — is shrinking as a result of human activity and energy consumption, and so are the populations of many large organisms. These declines cumulatively mean a loss in Earth's overall biomass. But there was hope for the future of the Earth.

"I think bad things lie ahead for humans and society for sure," said O'Connor. "But the planet is not going to implode, or disappear. Life on the planet will go on and most of the things we're accustomed to — biologically, ecologically — will carry on. I personally find that optimistic."

Along with sustainability, the course emphasized fundamental principles of complex systems, such as measures of sameness and the limits of computability, along with forays into algorithmic fairness, cascading failures in the power grid, and the power of Big Tech and its threat to democracy.

Participants brought their openness and creativity to the course, and a dynamic group of colleagues emerged. "Complexity Interactive was the missing piece of my journey as it built a vibrant community of complex systems researchers with whom I expect to keep learning, sharing, and collaborating," said participant Tamiris Santos, a postdoctoral fellow from Federal University of Rio Grande do Sul (Brazil).

SFI's live online course Complexity Interactive focused broadly on sustainability. (Image: collage by Carrie Cowan)

Collaboration, many students concluded, is at the heart of what it means to be useful. Complexity science is a powerful toolbox, but to apply it meaningfully to climate change mitigation and sustainability policies requires domain-specific expertise. Program Director, SFI External Professor Miguel Fuentes, explained, "The idea is not that the complexity scientist will do the policy 'thing.' Rather, they will be there on the team." Through such teamwork — with fellow researchers, policymakers, governments, educators, journalists, and the public — complexity scientists are not only useful, but essential.

Bridging the dogma divide in the origins of life

Ask a PI — the principal investigator leading a science grant — studying the origins of life about how it all began and you may get some forceful answers. But exactly which answers depends on the intellectual camp the PI belongs to. For example, some origins of life researchers work in an "information-first" framework, in which genetic information plays the leading role. For others, energy acquisition or "encapsulation" are the characteristics of life that likely arose first.

To an outsider, these ideas might seem like different parts of the same elephant, but the divisions have become deep enough that early career researchers worry about winding up in the wrong camp.

Organisms found in a drop of water, as illustrated by Agnes Catlow, in her book "Drops of Water: Their Marvellous and Beautiful Inhabitants Displayed by the Microscope" (Image: Public Domain Review)

Maria Kalambokidis, a graduate student at the University of Minnesota, says, "If one of us is proposing research that falls outside of some of this dogma, and if it's reviewed by a panel of reviewers that subscribe to a particular hypothesis for origins of life, will the research get shot down?"

One solution, she and other early career researchers in the field believe, might be to intentionally foster a community that heals divisions, promotes cross-pollination, and includes new voices from, say, biology or physics. To that end, Kalambokidis, along with SFI Postdoctoral Fellows Natalie Grefenstette and Cole Mathis, co-organized a March 9-11 meeting at SFI titled "New Frontiers in the Origins of Life." Some three dozen graduate students and postdocs gathered to bridge the dogma divide and examine their own biases and dogma.

Given how little we can know for sure about the origins of life on Earth, let alone elsewhere in the universe, Grefenstette hoped participants would engage in constructive conversations about what successful research looks like.

As Kalambokidis jests, "I think what's surprising for people who don't study the origins of life is, how could you have dogma about something that you hardly know anything about? Really, you know, we don't know how life emerged."

This workshop was co-organized by Caitlin McShea, program manager for the National Science Foundation Grant Number 1745355, under the Research Coordination Networks (RCN) program (RoL: RCN for Exploration of Life's Origins), which funded the meeting.

Complexity Postdocs come together after pandemic-induced hiatus

After a two-and-a-half-year pause, the eighth bi-annual JSMF–SFI Postdocs in Complexity conference reconvened at SFI April 6-8. The meeting included 34 James S. McDonnell Foundation Fellows from around the world and 13 Postdoctoral Fellows from the Santa Fe Institute.

"This meeting brings together early career complexity scientists who are at the top of their field and provides them with an opportunity to build a network for their future careers," says Hilary Skolnik, SFI's longtime Postdoctoral Fellows Program Manager. "The collaborative, interactive nature of the conference wasn't something we could easily replicate over Zoom." The short monthly virtual meetings over the past two years meant many of the participants had met online, but Skolnik says, "the whole focus for this conference was interactivity and networking."

In a two-part session called "You never know when to expect the Spanish Inquisition," journalists and media experts Sandy Blakeslee, Alex Witze, Mary-Charlotte Domandi, and Ned Judge provided guidance on how to handle any kind of interview. Then, following a COMPASS science communication training session, participants used improvisation to conduct mock interviews.

"This offered a way for them to practice their newly acquired interview skills with real journalists," says Skolnik. "It's about communicating their science effectively and more strategically."

The postdocs participated in another form of science communication through discussions with SFI Fractal Faculty member Stuart Firestein (Columbia University), who is writing his third book. Through back-and-forth conversations, the postdocs got a window into the process of writing a popular science book — this one on optimism — and Firestein received input from scholars from a range of disciplines.

Cross-discipline dialogues are part and parcel of meetings at SFI, but many of the Complexity Postdocs have worked primarily at universities with traditionally bounded departments. Any complexity scientist must know how to work across disciplines and to handle conflicts and differences of opinions when they invariably arise. During the three-day gathering, the fellows worked with SFI's Director for Education Carrie Cowan and Research Development Director Susan Carter to practice negotiation and conflict-resolution skills.

At the heart of the Postdocs in Complexity conferences is a quest to build best practices in complex systems research and an active networked community, says Skolnik. "We're exploring 'What does it mean to be a complex systems scientist?"

At SFI, that often means creative research collaborations. To conclude the meeting, the postdocs had the opportunity to propose a working group that, if accepted, would be fully funded and held at SFI.

The meeting was funded by the James S. McDonnell Foundation Grant Number 220020541.

Wheat from chaff: looking for real patterns

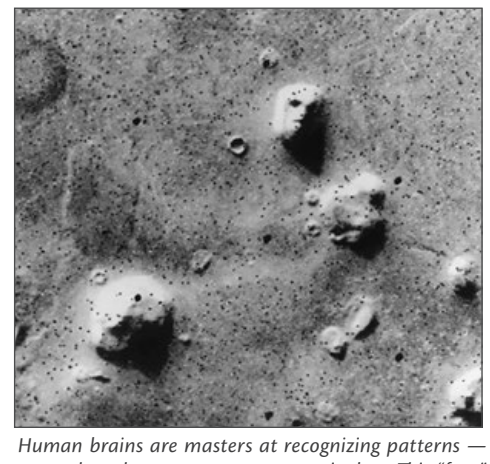
To advance research on topics from climate change to machine learning, scientific models are crucial. These models often reveal patterns, but humans also have a tendency to see patterns everywhere, even where there are none. How can researchers recognize which patterns are real and which ones are not? Which kinds of real patterns are most useful to science?

These are some of the questions that philosophers and scientists from various disciplines explored in a virtual SFI workshop on "Real Patterns in Science and Cognition" held February 28-March 4. The workshop was organized by SFI Postdoctoral Fellow Tyler Millhouse, along with SFI External Professor Daniel Dennett (Tufts University), Don Ross (University College Cork, University of Cape Town, and Georgia State University), and Steve Petersen (Niagara University).

Dennett first introduced the concept of real patterns in 1991. "Since then, it's sort of slowly been building up steam, and people have been more and more interested in applying it to different areas of research," says Millhouse. "The workshop was designed to bring together people whose work either does try to extend real patterns in this way or is adjacent to it."

The researchers came away with fresh insights into the connections between their lines of inquiry and a more nuanced understanding of real-patterns thinking. For example, four participants from different disciplines, including Millhouse, all spoke about coarse-graining — finding ways to simplify complex data so that it can be more easily understood — but only one of those talks directly dealt with real patterns. Yet "there was surprising convergence in our talks," Millhouse says. "In particular, we all saw, in different ways, this process of coarse-graining as vital to revealing important patterns in the world, and we were able to share and learn from quite different examples of how this happens — from patterns of social dominance in non-human primates to the patterns in machine-learning datasets. These are examples I will draw on in my own work, and they will add important nuance and breadth to the way I think about real patterns."

This meeting was supported by National Science Foundation Grants 2020103 and 2139983.



Human brains are masters at recognizing patterns — even when those patterns are meaningless. This "face" on Mars, captured by NASA's Viking 1 in 1976, is not evidence of alien life, as some speculated, but rather, simply a Martian mesa. (image: NASA)

ACHIEVEMENTS

SFI External Professor **Mahzarin Banaji** received an Atkinson Prize in Psychological and Cognitive Sciences from the National Academy of Sciences.

External Professor **Marco Buongiorno Nardelli** was named "Regents Professor," the highest recognition for a faculty at the University of North Texas.

SFI External Faculty Fellow and Science Board Member **Marcus Feldman** received a Lifetime Achievement Award from the Society for the Study of Evolution.

External Professor **Orit Peleg** received a 2022 Cottrell Scholar Award through the Research Corporation for Scientific Advancement.

ASU-SFI Biosocial Complex Systems Fellow **Stefani Crabtree** and SFI External Professor **Devin White** were awarded one of three HPC Innovation Excellence Awards from Hyperion Research's High Performance Computing User Forum.

SFI Schmidt Science Fellow **Yuanzhao Zhang** received a Dissertation Award in Statistical and Nonlinear Physics from the American Physical Society.

The BBVA Foundation recognized SFI External Professor **Matthew Jackson** with a Frontiers of Knowledge Award in economics and Science Board Member **Simon Levin** with a Frontiers of Knowledge Award ecology and conservation.

The Albert Einstein College of Medicine recently announced **Aviv Bergman** as the director of its new Institute for Advanced Studies in the Life Sciences.


Mahzarin Banaji


Marco Nardelli


Marcus Feldman


Orit Peleg


Stefani Crabtree


Devin White


Yuanzhao Zhang


Matthew Jackson

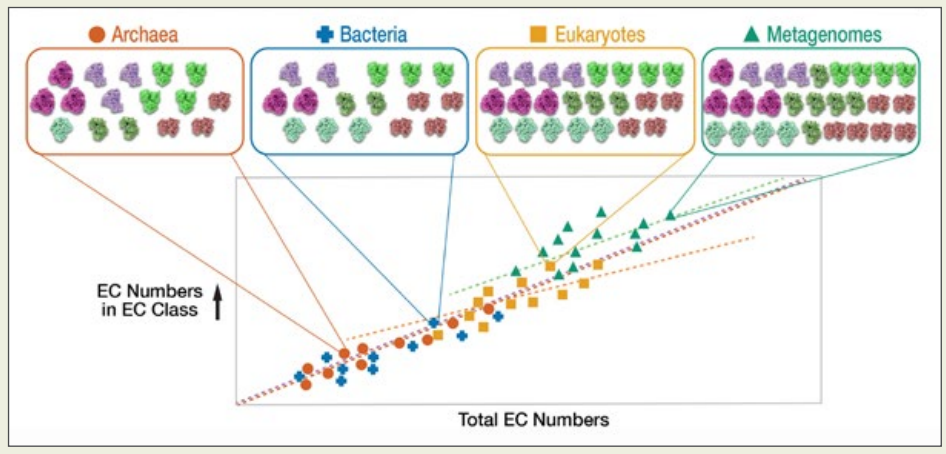

Simon Levin


Aviv Bergman


Sean Carroll

Sean Carroll announced his upcoming position as Homewood Professor of Natural Philosophy at Johns Hopkins University.

RESEARCH NEWS BRIEFS



Enzyme classes across the life spectrum. *Understanding how classes of enzymes that perform different functions scale in different organisms on Earth could help researchers predict and identify life elsewhere in the universe even if it looks very different from life as we know it. (image: from Figure 1 in "Scaling laws in enzyme function reveal a new kind of biochemical universality," PNAS)*

LIFE'S MATHEMATICAL SIGNATURES

In the quest to define life, the primary reference point is life on Earth. Yet astrobiologists suspect that the search for life may require that we look beyond the lifeforms we know. We need new tools for predicting and identifying features of life as we don't know it, says SFI External Professor Sara Imari Walker. In a new study published in *PNAS*, a team of researchers that includes Walker and SFI Professor Chris Kempes, identifies universal patterns in the chemistry of life that do not appear to depend on the molecules we find in Earth life. The team discovered various scaling laws between the number of enzymes in different enzyme classes and the size of an organism's genome. These kinds of patterns might be one of life's mathematical signatures.

Read the paper at doi.org/10.1073/pnas.2106655119

INFORMATION & SCALING THRESHOLDS IN HUMAN SOCIETIES

At certain points in human history, societies experience revolutions in collective computation — the methods for storing and sharing information that shape decisions in collective behavior. Those revolutions, in turn, can shape the scale of societies that adopt them.

In a recent paper in the *Journal of Social Computing*, SFI Professor David Wolpert, SFI External Professor Tim Kohler, and their colleague, Darcy Bird built on past research to explore patterns of change to collective computation that occur in human history. They identified two significant thresholds that relate scale to changes in collective computation. First, they observed a scale threshold: before information systems, such as writing systems, emerge, societies must grow to a certain scale. Second, they found an information threshold, which, when crossed, enables societies to grow in scale.

Read the paper at doi.org/10.23919/JSC.2021.0020

SCALE MATTERS FOR PREDICTING INFECTIOUS DISEASE BEHAVIOR

What's the best scale to use to study the spread of disease? With COVID-19, we've seen that it's not at the scale of a country or even a state — the variation from county to county makes that clear. A new study in *Nature Communications* shows that we may have to go all the way down to a single city block, and that the key feature is to choose areas with a similar population density.

SFI External Professors Aaron King and Mercedes Pascual and collaborators studied the spread of a new variety of dengue fever over two years in Rio de Janeiro. They analyzed the size of the second peak of transmissions relative to the first. In areas with both particularly high and particularly low densities, the second peak tended to be worse than the first, whereas in areas with intermediate densities, the ratio of the second peak to the first was not as high. Their findings contribute to understanding the fundamental drivers for vector-borne diseases like dengue, as well for other infectious diseases like the seasonal flu and COVID-19.

Read the paper at doi.org/10.1038/s41467-022-28231-w

SCALING OF HUNTER-GATHERER CAMP SIZE AND HUMAN SOCIALITY

From hunter-gatherer encampments to modern cities, permanent human settlements tend to densify as the population grows, while mobile human settlements do the opposite. New research in *Current Anthropology* by SFI's Luís Bettencourt and Scott Ortman, with coauthors José Lobo, Todd Whitelaw, Polly Wiessner, and Michael E. Smith, explores these dynamics and the conditions that might lead impermanent, spread-out communities to transition to denser, stationary settlements.

"This paper represents an extension into the hunter-gatherer lifestyle of the analytical framework we have used to study cities and urbanization," says Lobo. "The transition from the hunter-gatherer lifestyle to sedentism is one of the most important transitions in the history of our species and a very active area of research."

Read the paper at doi.org/10.1086/719234

FOR MORE RESEARCH NEWS BRIEFS, VISIT SANTAFE.EDU/NEWS


Like most things in 2020 and 2021, SFI's summer Undergraduate Complexity Research program went virtual due to the pandemic. This January, 14 students from the two summer cohorts gathered at SFI for a weeklong research visit to continue their projects, meet with resident researchers, participate in scientific discussions and workshops, and deepen their connections with one another and the SFI community. (Photo: Carla Shedivy)

Parallax
SPRING 2022
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