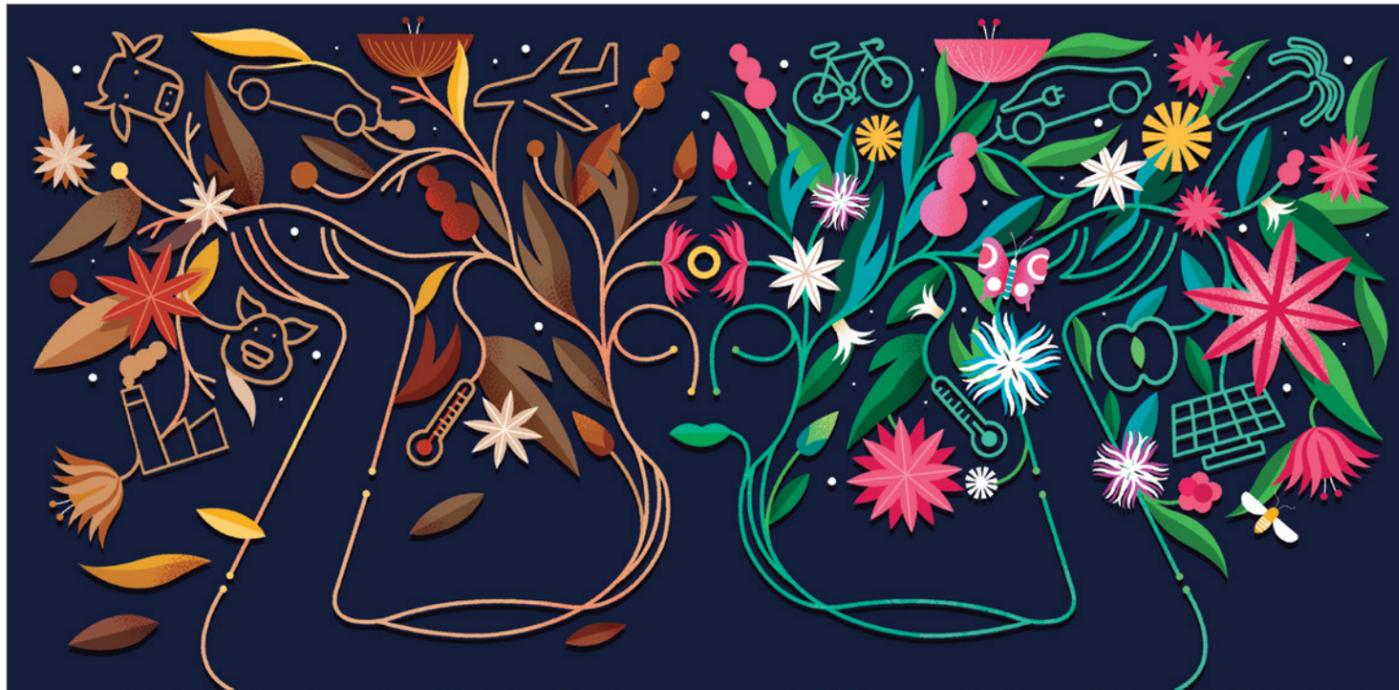




Parallax

WINTER 2025-2026

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Green values can be crowded out or cultivated. Well-designed policies can cultivate green values if they appear effective and non-intrusive, finds a new study by SFI Complexity Postdoctoral Fellow Katrin Schmelz and SFI Professor Sam Bowles. (image: Irene Pérez)

When climate policies impact “green” ethics

A popular vision of life after climate action looks like vegetarians riding bikes, city centers without cars, and people foregoing air travel. But a paper published in *Nature Sustainability* finds that climate policies targeting lifestyle changes (say, urban car bans) actually may weaken people’s green values, thereby undermining support for other needed environmental policies.

“Policies don’t just spur a target behavior. We find that they can change people’s underlying values: leading to unintended negative effects, but also possibly cultivating green values,” says SFI Complexity Postdoctoral Fellow Katrin Schmelz, lead author on the study.

Schmelz, a behavioral economist and psychologist who also holds an Associate Professorship at the Technical University of Denmark, began gathering data while at the University of Konstanz in Germany. Along with SFI Professor and economist Sam Bowles, she surveyed more than 3,000 Germans representative of the country’s demographics,

asking about climate policies and, for comparison, COVID-19 policies.

The survey yielded evidence that well-intended, but poorly designed, mandates can make even “green” citizens less green. Restrictions that promote carbon-neutral behavior, like urban car bans, may trigger strong negative reactions, even among people who would voluntarily choose sustainable lifestyles.

This erosion of existing values is a clear example of what’s known in psychology and economics as the “crowding-out effect.” A person’s aversion to control “crowds out” their pre-existing motivation to follow a green lifestyle — for example, riding their bike, walking, and taking public transportation, or being more mindful when heating or cooling their home. “These crowding-out effects are big enough that policymakers should worry,” says Bowles.

Another key finding, which surprised the authors, was a 52% greater negative response to climate mandates than to COVID-19 mandates. “We saw incredible hostility in the U.S.

and other countries towards controls during the COVID-19 pandemic, hindering the implementation of much-needed public policies. It looks like the climate case could be much worse,” says Bowles. “The science and technology to provide a low-carbon way of life is nearly solved. What’s lagging behind is a social-behavioral science of effective and politically viable climate policies.”

The research Schmelz and Bowles have begun is already seeing applications. Last April, policy experts and researchers from various disciplines met at SFI to discuss preliminary findings from the study and brainstorm how to design policy that can encourage green values.

There is reason for optimism, the study shows. Mandate resistance was less for people who felt that policies were effective, didn’t restrict their freedom of choice, and were not intrusive on their privacy or their body. “We found three conditions that minimize opposition to mandates, and may even cultivate, rather than

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Constructing a science of stories

From *Beowulf* to *Pride and Prejudice* to the classic sitcom *Friends*, all stories share a common purpose: to convey knowledge about how to navigate the world.

“Stories are everywhere,” says SFI External Professor Peter Dodds, a systems scientist at the University of Vermont. “Even sports, or the differential equations that describe fluid dynamics, are kinds of storytellers. Stories that people tell and retell almost always involve characters and events that are connected and unfold over time, wrapped around essences of power, danger, and survival.”

Dodds co-organized a working group, “Towards a Data-Driven Science of Stories,” held at SFI December 10–12. Computer scientists, folklorists, physicists, marketing experts, cognitive neuroscientists, economists, mathematicians, psychologists, and other researchers convened to connect different approaches to understanding stories.

“We wanted to illuminate the spectrum of stories across time and cultures, just like other fields have found spectrums of stars, species, or words,” says Dodds.

In a world where large language models like ChatGPT achieve feats no human can — they are conceivably, capable of ingesting the entire *New York Times* archive or a century’s worth of literature — it might seem easy to pick out story patterns. But building a truly cohesive science of stories requires tools from complex-systems research.

“Explaining a joke kills the humor; we don’t want to make stories dull by studying them. Our working group explored new explanatory models and computational tools, drawing from complex-systems science, to develop a science of stories that honors what a story is, and doesn’t reduce it to a bag of words,” says Sam Zhang, a University of Vermont statistician and recent SFI Applied Complexity Postdoctoral Fellow.

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Historical forces driving human-rights expansions

For most of human history, large societies have drawn clear lines between people who belong to the in-group and those who do not. These lines determine who is recognized, protected, or granted status, and who is excluded. But starting in the Enlightenment period, European societies began relaxing the rules around who was granted fundamental rights and protections, a development many scholars see as essentially unique in human history, and one that has grown steadily over the past several centuries and continues today.

A December 15–17 SFI working group explored whether this expansion of human rights truly occurred in the way it seems to have, whether it is unique, and what might have caused it.

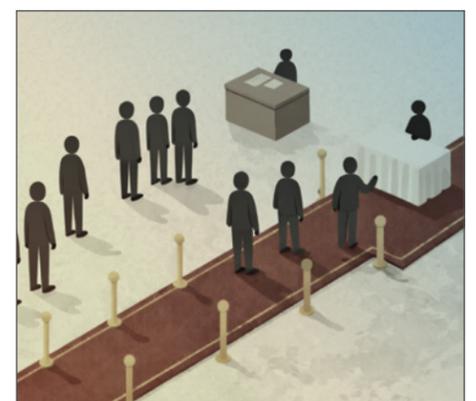
“This expansion seems to have happened once, and only once,” says SFI Professor David Wolpert, who organized the meeting with Sam Zhang (University of Vermont), a recent SFI Applied Complexity Fellow. “Our first task is to confirm whether that’s true.”

To approach the problem, the group adopted a shared, operational definition of this human-rights expansion: the loosening, over time, of the criteria for who counts as in-group and who counts as out-group. “We’re not trying to measure an ‘amount’ of human rights,” Wolpert says. “We’re defining expansion as a shrinking of the criteria elites use to decide who is in the in-group.” These changes can often be seen in laws and court decisions, such as shifting rules

about who is allowed to vote. The group’s first goal was to see whether broader historical data can show how these criteria have evolved across all societies and eras.

This goal has only recently become feasible, due to the growing availability of large-scale historical datasets that systematically compile information on social and political organization of human societies across centuries. Sources like the Seshat: Global History Databank, led by Peter Turchin, a faculty member at the Complexity Science Hub in Vienna, may make it possible to test long-held assumptions about when and how rights expanded in different

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A recent working group examined how societies have defined who belongs, and how those definitions have shifted over time. (image: Unsplash)

THE PROBLEM OF TRANSLATION AND SEMANTIC DARK MATTER

“Chapman’s translation has often been praised as eminently Homeric. Keats’s fine sonnet in its honour everyone knows; but Keats could not read the original, and therefore could not really judge the translation. Coleridge, in praising Chapman’s version, says at the same time, ‘It will give you small idea of Homer’ . . . I confess that I can never read twenty lines of Chapman’s version . . .”

— Matthew Arnold
On Translating Homer (1861)

“Is it possible that the string-theory fashion is beginning to taper off? It is my own view that the representation of string theory has for many years been excessive . . . its stranglehold on developments in fundamental physics has been stultifying, and has in my view hindered the development of other areas that might have had more promise of ultimate success.”

— Roger Penrose
Fashion, Faith, and Fantasy (2016)

In an effort to make the progress of science smooth and cumulative, a number of physicists and philosophers in the first half of the 20th century endeavored to extend Niels Bohr’s “correspondence principle,” which originally connected quantum mechanics to classical mechanics by exploring infinitesimal or infinite limits. This was subsequently generalized into a system of correspondences aimed at establishing the unity of knowledge: searching for the simplest parameter space of a larger theory in which multiple different local theories apply. These generalized “correspondence principles” are, in effect, the desire for a “perfect” system of translation among theories in which, *ceteris paribus*, all local differences and histories are minimized and ignored, in order that epistemology might make neat slices through an omnivorous state space.

I call these local differences, histories, and latent variables the semantic dark matter of scholarship. Recall that dark matter is a rather mysterious and putative kind of matter, one that does not reflect light but has a gravitational effect. Semantic dark matter describes the invisible factors and processes that make models and theories work in a given context without threatening their basic assumptions. My purpose is not to dismiss dark matter, but to reveal the nature of its existence. And to encourage us to consider the possibility that, at some point, the causal efficacy of the invisible prompts us to consider new theories.

Darwin’s theory of evolution by natural selection plays the role of semantic dark matter in relation to the second law of thermodynamics, reconciling the local, and perhaps even transiently global, increase in functional order in the face of entropy increase. Game theory plays the role of semantic dark matter in the face of violations of Pareto efficiency (optimal solutions for all agents) in economic, ecological, and evolutionary processes.

In the philosophy of science, these “corrections” have been called auxiliary theories,

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Francis Spufford named SFI Miller Scholar



Francis Spufford, an internationally award-winning author of both fiction and nonfiction books, has joined SFI as a Miller Scholar. (image: Antonio Olmos)

“The idea is the hero.”
— Francis Spufford, *Red Plenty*

Francis Spufford, the author of numerous works of fiction and nonfiction, is the newest Miller Scholar at the Santa Fe Institute. “I recognized him as a kindred spirit,” says SFI President David Krakauer. “He is a metaphysician, a writer of ideas — ideas that move him into the absolute nexus of what is done at SFI.”

A Fellow of the Royal Society of Literature, Spufford teaches writing at Goldsmiths, University of London, and resides in his native Britain with his wife, the Reverend Dr. Jessica Martin, Dean of Chelmsford, and their younger daughter. He is the son of two lauded British professors: social historian Margaret Spufford and economic historian Peter Spufford. It was through his father that Francis first encountered the Santa Fe Institute, accompanying him in May 2004 to an SFI meeting concerning the network properties of the medieval economy.

“My father told me ‘there are these weirdos in New Mexico who want me to go talk about medieval trade,’” says Spufford. “And I said he had to go, and he had to bring me with him.”

As the child of two historians, it is not surprising that Spufford’s writing, both fiction and nonfiction, engages deeply with the entanglement of historical, economic, and social forces. He does so in his first novel, *Golden Hill* — a picaresque of a protagonist trying to cash in on a letter of transatlantic credit at the counting houses of colonial New York — and in his nonfiction book *Red Plenty*, with its narrativized, fiction-infused depiction of Soviet scientists struggling to make viable their planned economy.

“I have no mathematics,” says Spufford. “But I can see structural complexities and enjoy them very much as the subject for writing.”

I have a knack for pattern recognition, even if it takes me a while.”

Spufford’s work asserts the right of the artist to imagine the public and private lives of others, both in our own history and in alternative universes that reflect our own, as is the case with *Cahokia Jazz*, a hardboiled detective novel set in a 1920s Native metropolis, where history diverged when a different and less-lethal strain of smallpox arrived with Europeans to North America. Works of imagination such as these are akin to forms of scientific modeling, and any static in those depictions, any discussion that might arise, is very much the point.

“At SFI, we’re world builders,” says Krakauer. “We use different tools to do it: and Spufford’s orthogonal method through fiction, the elaborate edifice created by his imagination, reveals parallel insights to those we draw in complexity science.”

Spufford’s writing self-consciously defies categories of genre and mode. “This is not a novel,” he writes in the introduction to *Red Plenty*. “It has too much to explain, to be one of those.” Novel or not, *Red Plenty* utilizes all the novelist’s tricks to orient a reader in the hearts and minds of the Soviet engineers (most historical, some composite, some completely fictional) who are frantically trying to develop a computer powerful enough, and an algorithm optimal enough, to make their

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A ‘first date’ for neuromorphic computing and stochastic thermodynamics

The human brain is astonishingly efficient. It runs on about 20 watts, roughly the power required to keep a dim bulb lit. Over the last three decades, computer scientists in a field called neuromorphic computing have sought ways to replicate that energy efficiency in computing devices modeled on how networks of synapses process information in the brain. Recent years have even seen the production of neuromorphic computing chips from companies like Intel and IBM.

But there’s a tradeoff: That efficiency gain in neuromorphic chips comes at the cost of slower computing speed, says Shantanu Chakrabartty at Washington University in St. Louis. “We need to break this barrier,” he says. “Ideally you want to get more bang for the buck from the amount of energy you spend.”

Stochastic thermodynamics, a subfield of physics, may help. Researchers in the field study the energy cost of computation in systems out of equilibrium, which includes

modern computers. Bringing it into the world of neuromorphic computing is a natural pairing, says SFI Professor David Wolpert. “These fields have so much to say to one another.”

Wolpert and Chakrabartty, who met two years ago, organized a working group, held at SFI December 10–12, designed to give experts from both fields the opportunity to learn from each other and exchange ideas. The 13-person working group was supported in part by a grant from the National Science Foundation, which had requested the meeting.

After decades of work, said Chakrabartty, researchers have investigated many architectures in pursuit of what’s called the “neuromorphic advantage.” Even so, it’s still an aspirational approach, and there’s plenty of uncharted territory — especially in finding ways to harness the random noise and small-scale fluctuations that naturally arise during computation. “We just haven’t figured out how to exploit them efficiently,” says

Chakrabartty. “And that’s where stochastic thermodynamics comes in.”

Current neuromorphic approaches, says Wolpert, focus on the phenomenology — the observed performance — of the device, rather than the underlying physics. Stochastic thermodynamics points to a way to gain a deeper understanding. “This meeting was required for neuromorphic to really move forward,” he says.

One of the goals of the working group, Chakrabartty says, was to start a conversation in which researchers in neuromorphic computing could give the stochastic thermodynamics community an overview of the state of the art in their field — and vice versa.

“This was a first date between the two communities,” says Wolpert — one that went very well. As soon as participants from each field learned what the others were doing, they grasped the connection so quickly it seemed obvious, he says. The meeting concluded with plans for future collaborations and meetings. ☞

How reliable is Normalized Mutual Information?

When scientists test algorithms that sort or classify data they often turn to a trusted tool called Normalized Mutual Information (NMI) to measure how well an algorithm’s output matches reality. But according to new research, that tool may not be as reliable as many assume.

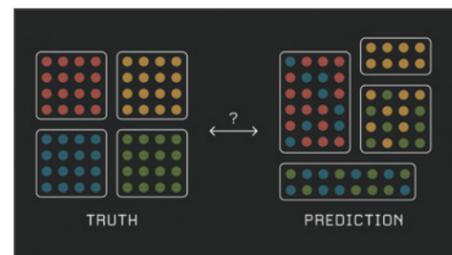
In a paper published in *Nature Communications*, SFI Postdoctoral Fellow Max Jerdee, Alec Kirkley (University of Hong Kong), and SFI External Professor Mark Newman (University of Michigan) show that NMI — one of the most widely used metrics in data science and network research — can produce biased results.

“Normalized mutual information has been used or referenced in thousands of papers in the decades since it was first proposed,” Newman says, “but it turns out that it can give incorrect results, and the errors are large enough to change scientific conclusions in some cases.”

Suppose researchers are developing algorithms to classify medical conditions based on patient symptoms. One model might correctly

identify diabetes but treat all cases the same, while another is better at distinguishing between type 1 and type 2, but completely misses the diabetes diagnosis 10% of the time, therefore having a greater error margin. In situations like this, researchers need a way to say which model’s predictions give more information about the true condition. Mutual information helps with that, measuring how much a model’s output reduces the uncertainty about the correct classifications. Researchers often normalize that measure so it falls between 0 and 1, which makes different problems easier to compare. Yet Jerdee and colleagues found that this normalization introduces two major biases.

First, it can reward algorithms that over-divide data, inventing extra categories and appearing overly accurate. Second, commonly used normalization methods can introduce a further bias toward artificially simple algorithms. Both effects can distort comparisons, especially in complex problems where the “true” grouping is not straightforward.



When different predictions capture different aspects of the same underlying structure, how should they be compared? New work shows that a widely used metric often answers that question in biased ways. (image: Max Jerdee)

To address these issues, the team developed an asymmetric, reduced version of the mutual information metric that eliminates both sources of bias. When they applied their measure to popular community-detection algorithms, they found that, while standard NMI can point researchers to different “best” algorithms depending on how it’s calculated, their

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SFI welcomes new postdoctoral fellows

SFI postdoctoral fellows are selected from around the world for their intellectual curiosity, quantitative and qualitative rigor, and multi-disciplinary creativity. At the Institute they enjoy exceptional freedom to pursue new questions and collaborate with foremost thinkers in our international research network as they prepare to become tomorrow's scientific leaders. All fellows participate in a unique training program designed to develop their scientific, communication, and leadership skills. Most go on to hold faculty positions at major universities and research

institutions, where they serve as lifelong ambassadors for the philosophies and methodologies of complexity science.

This fall and winter, SFI welcomes two new Complexity Postdoctoral Fellows and one Visiting Complexity Postdoctoral Fellow supported by the Omidyar Network, and two Program Postdoctoral Fellows working closely with resident professors at SFI on grant-funded projects.



JACOB CALVERT

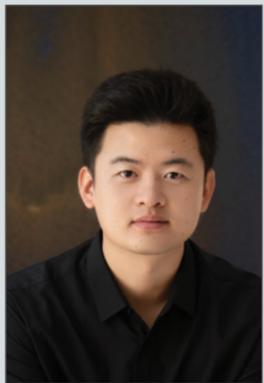
The human brain is remarkably good at detecting patterns in the world around us. We notice behaviors, rhythms, and recurrences, and often build analogies to explain them. But not all of these intuitive ideas about nature hold up under mathematical scrutiny.

Visiting Complexity Postdoctoral Fellow Jacob Calvert is interested in which of those ideas can be made precise. A mathematician and data scientist, he studies how collective behaviors emerge and recur across different physical and biological systems. "I'm interested in simple, direct questions about nature that are difficult to answer precisely," he says. "I try to see which analogies actually hold up under the microscope of precise mathematics."

His research aims to test the structural similarities of collectives across physical scales and scientific domains. Drawing on a wide-ranging academic background, he uses tools from probability theory, statistical physics, and the study of collective behavior to bring mathematical clarity to ideas that often begin as a metaphor. In a parallel career as a data scientist at Dascena, he led the development of the first sepsis-prediction algorithm shown to improve patient outcomes in a clinical trial.

Calvert is exploring open questions around entropy production in non-equilibrium systems and how the behavior of collectives changes with scale. He's also interested in connecting his probabilistic approach to non-equilibrium systems with recent developments in stochastic thermodynamics, and in engaging with areas where his current research could benefit from SFI's broader expertise.

He holds a Ph.D. in statistics from UC Berkeley, M.Sc. degrees in mathematics (University of Bristol) and theoretical physics (University of Oxford), and a B.S. in bioengineering from the University of Illinois. He is also a postdoctoral fellow at Georgia Tech. Calvert traces his path to SFI back to reading *Complexity: A Guided Tour* by Melanie Mitchell as a college student. "It just changed my life," he says. "The book was raising those questions about nature that were the most interesting, somehow the most obvious and fundamental, but the most difficult to answer."



SHUHAO FU

Artificial-intelligence systems have made remarkable progress in recent years, but they still struggle with the kind of flexible, relational reasoning that comes naturally to humans. Program Postdoctoral Fellow Shuhao Fu studies how to bridge that gap.

With a background in both machine learning and cognitive science, Fu designs models that replicate human-like abilities such as analogy-making and compositional understanding. During his Ph.D., he combined behavioral experiments with structural AI models to study how humans and machines perceive and reason about relationships. "I'm more into finding out why models fail," he says, "not just making them score better on some metrics."

His recent research explores how AI can move beyond simple object detection to represent relationships between elements, such as how objects are arranged, how they interact, or how a concept applies across different contexts and scenes. He has also applied AI tools in health-related domains, from collaborating on a project at UCLA that used large language models to assist in depression screening, to earlier work at Johns Hopkins University developing methods to detect tumors in CT scans.

At SFI, he will be working closely with SFI Professor Melanie Mitchell, starting with the development of a model associated with the Abstraction and Reasoning Corpus challenge, a benchmark for artificial intelligence that tests a model's ability to reason and generalize abstract concepts from a few visual grid-based input/output examples. Furthermore, he's interested in using structural representations and new training approaches to help AI systems perform more human-like generalization. Fu earned a B.S. in computer science and mathematics from the Hong Kong University of Science and Technology; from UCLA, he received an M.S. in statistics and an M.A. and Ph.D. in psychology.



MAX JERDEE

SFI Complexity Postdoctoral Fellow Max Jerdee builds statistical tools to study the structure of networks — not just who connects to whom, but how patterns of hierarchy and community vary across systems. "There are many different networks we could consider," he says. "Networks of friendship, networks in your brain, networks of transportation . . . and somehow you can come up with a unified language to talk about all these things." His research develops that language: mathematical and statistical tools for revealing structure in complex systems.

Jerdee focuses on building interpretable, unbiased methods for analyzing network data. Using tools such as Bayesian inference and related probabilistic approaches, he develops models that identify network structures while rigorously quantifying uncertainty. "I think a lot about how our methods shape what we believe we see in data," he says. "If the instrument is biased, everything downstream will be, too."

Building on this approach, his recent work compares systems with different degrees of hierarchy, from strongly hierarchical animal-dominance networks to more evenly matched outcomes in sports leagues, and how the same mathematical framework can describe both.

At SFI, Jerdee plans to extend these tools into a broader framework for comparing network organization and for investigating the mechanisms that give rise to it. He also develops algorithmic improvements — drawing on techniques from statistical physics — that make it possible to apply these models more efficiently and at larger scales, opening new possibilities for studying how structure and function coevolve in complex systems.

Jerdee earned an A.B. in physics from Princeton University and a Ph.D. in physics at the University of Michigan, where he worked with SFI External Professor Mark Newman. His earlier research ranged from astrophysical-image analysis to high-energy theory before turning to network science, applying the same mathematical curiosity to the social and biological systems that shape our world.



JORDAN KEMP

Figures such as a country's gross domestic product or a city's population size represent organizational and individual decisions over time. These statistics are useful for policymaking, but they hide the complexity that stems from regional variations in choice.

Program Postdoctoral Fellow Jordan Kemp hopes to leverage the richness of urban-growth data by capturing patterns of behaviors among different groups at various scales, from the individual to the population level. "Historically, researchers sought to develop universal models," Kemp says. "To connect these models to individual experiences, we need to measure and understand local differences."

Kemp approaches growth as an adaptive process: a result of decision-making that varies by place and context, with large-scale implications. Under the theme of emergent engineering, his research at SFI will draw on fields like ecology that have developed methods for tracking how populations grow and change over time. He seeks to build a common language that connects both individual agency and systemic forces to help make human systems more resilient to future challenges.

"For the sake of policymaking, it's important to not just understand the state of the world, but how that relates to underlying processes of choice in changing environments," Kemp says. "Existing disciplines can each tell us pieces of that puzzle, but complex systems can help us understand how they come together."

SFI External Professor Luís Bettencourt advised Kemp during his Ph.D. in physics at the University of Chicago, where he studied adaptive growth and cooperation. At SFI, Kemp will work with SFI President David Krakauer and Professors Chris Kempes and Cris Moore to carry forward the work from his Ph.D., as well as his recent postdoc at INET Oxford, where he used growth to study compositional changes in urban data.



MAIKE MORRISON

Across biology — from microbial communities to cancer tumors to ancient human populations — researchers measure diversity in ways that shape how we understand life. But those measurements are often discipline-specific, limiting their ability to reveal deeper patterns across systems.

Complexity Postdoctoral Fellow Maike Morrison builds mathematical tools to quantify and compare biological variation. Her work draws on ecology, population genetics, and information theory to study the structure, diversity, and stability of populations — whether those populations consist of species in an ecosystem, microbes in the gut, ancestry fractions in humans, or even assets in a financial portfolio. As an example, her doctoral research at

Stanford University produced methods and software for analyzing mutational diversity in cancer, heterogeneity in microbiomes, and ancestry variability in human populations.

At SFI, Morrison will continue building cross-cutting frameworks to understand biological variation across fields and scales. Beginning with projects in population genetics, she plans to develop models that better reflect the genetic diversity within groups and challenge overly broad assumptions about differences between them. She's also applying methods from biology to study heterogeneity in economic systems, including a project analyzing supply chains in Ecuador.

"Part of my work in population genetics is to develop better data-science approaches that allow us to emphasize the diversity within each human population and the similarities across populations, rather than treating each group as a monolith," she says.

Morrison earned a B.S. in mathematics from the University of Texas at Austin in 2020, where she worked with Professors Mark Kirkpatrick and SFI External Professor Lauren Ancel Meyers as a member of the Dean's Scholars Honors Program. She completed her Ph.D. in ecology and evolutionary biology at Stanford University, supported by an NSF Graduate Research Fellowship and a Stanford Graduate Fellowship. 🦋

CLIMATE POLICY (cont. from page 1)

crowd out, green values," says Schmelz. "People are more open to policies that they think are effective in reducing CO₂ emissions, and that they don't perceive as privacy-intrusive. People also respond much more positively if they don't feel that a policy restricts their freedom — so in Germany, there is less opposition to limitations on short-haul flights compared to other policies, and this may be because the European train network provides an adequate alternative, which may not be the case in the U.S., for example." 🦋

ALGORITHMIC PERFORMANCE BIAS (cont. from page 2)

revised measure offers a more consistent and trustworthy comparison. By correcting this metric, the authors hope to improve the reliability of comparisons across any fields where clustering or classification play a central role. "Scientists use NMI as a kind of yardstick to compare algorithms," Jerdee says. "But if the yardstick itself is bent, you might draw the wrong conclusion about which method performs better." 🦋

What we're reading

Books on the topic of Language

In 2017, Cormac McCarthy published an essay in *Nautilus* magazine on the mysteries of the unconscious, the origins of language, and the extensive gap between the two. Entitled “The Kekulé Problem,” the essay asks why the unconscious — which clearly understands language and also performs most of our thinking — does not give us answers to our difficult problems in linguistic terms. One of his key points was that language is not a biological system but a human invention: something useful, but not necessary, that originated as an intentional innovation rather than an adaptation.

“The central idea of language,” he wrote, is “that one thing can be another thing. It is the idea that Helen Keller suddenly understood at the well. That the sign for water was not simply what you did to get a glass of water. It was the glass of water. It was in fact the water in the glass.”

Today we are dealing with a new form of intelligence that has not innovated a language on top of its biological toolkit, but instead appears to be emerging from human language itself: the large language model. Questions we do not yet know how to answer are proliferating. Can true intelligence emerge from language alone? What is it in our language that makes it powerful enough to create what some would consider a new life form? Can a total language aggregator distinguish truth from falsehood, signal from noise? Does meaning play a role in its output? Can it think? Can an unconscious develop out of language rather than the other way around?

We can only speculate about what Cormac McCarthy would say on these topics. In his absence, we offer three books about the enigma of language — not only concerning its origin and essence, but also its strengths, weaknesses, and even how its weaknesses may be strengths in disguise (or vice versa).

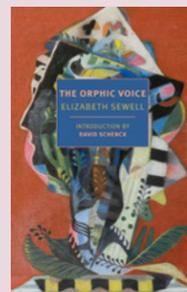
On the Origin of Language
Jean-Jacques Rousseau & Johann Gottfried Herder

This volume brings together identically titled essays by the 18th-century thinkers Rousseau and Herder.

Rousseau claims that language originated in the social passions rather than from mere utility. Herder claims that we think in language, and that even for an individual in isolation, language would develop out of the human capacity for reflection. Whichever essay a reader finds more convincing, each is an exceptional piece that stands in counterpoint to the other, and each raises questions that surpass the explicit arguments of its respective author.

The Orphic Voice
Elizabeth Sewell

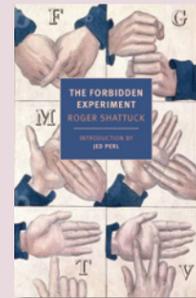
A rich but ultra-focused inquiry into language as the key human activity,



The Orphic Voice is a must-read for anyone interested in myth, poetry, history, or the philosophy of science. Examining references to the myth of Orpheus among biologists, poets, and theorists, Sewell addresses the challenge the myth contains, namely to see how “language and mind, poetry and biology meet and bear on one another.” Her ultimate claim is that poetry and science are not distinct enterprises, but instead form a “double discipline.”

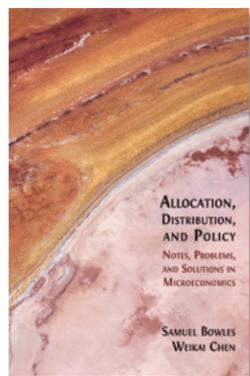
The Forbidden Experiment
Roger Shattuck

This is the true story of a “wild child,” discovered in 1900s France after years of lone survival in the wilderness. Equally, it is the story of the medical student who attempted to teach the boy how to communicate. All along, Shattuck — initially a Proust scholar — connects the intriguing narrative to questions about the mind and language that, to this day, obsess almost every philosopher, cognitive psychologist, and sociologist. 📖



Allocation, Distribution, and Policy

Review by SFI External Professor Suresh Naidu (Columbia University)



Over the past 40 years, the field of microeconomics has gone through a revolution in real-world applications, yet the theoretical models taught in Ph.D. coursework have been slow to catch up. In a new textbook, SFI Professor Sam

other is more personal, as I was one of a long line of teaching assistants who wrote up solutions to Economics 700 problem sets, which Bowles taught at UMass-Amherst over 20 years ago. I recognized many of the problems in *Allocation, Distribution, and Policy* as developing themes and ideas that Bowles introduced in his 2004 textbook *Microeconomics: Behavior, Institutions, and Evolution*, but also touching on the many developments since then.

Problem sets are one thing that distinguishes economics from most of the other social sciences. Even at the introductory level, to learn economics is to learn to solve problems, cranking through enough math that you develop an intuition for what is fundamental and what is contingent in an economic model. You learn to think like an economist: trying to strip things down to objectives and interactions between agents, be they individuals, classes, or nations. You build a repertoire of formal analogies — prisoner's dilemma, battle of the sexes, Nash bargaining, tragedy of the commons, public goods, principal-agent problems, supply and demand — all of which become mental bicycles, devices that amplify human effort, for the practicing social scientist. Math is the vernacular, but the thought process is economics. After a bit of practice,

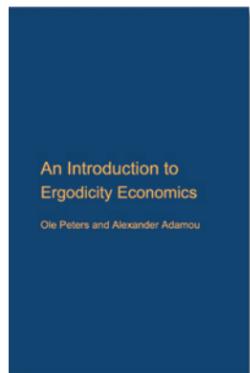
thinking through the economics winds up being a short-cut through algebra, and, conversely, many math whizzes who initially thought economics was simple eventually learned that technical ability and economic intuition are only partially substitutable.

What is different about this particular book of problems is that they illustrate where economics is now, as opposed to where it was 40 years ago. The teaching of economics at the Ph.D. level is a set of canonical models at a very high level of abstraction: consumers and firms, game theory, general equilibrium, and mechanism design. But there is little that relates these models to the actual economy. The intuitions built by the exercises in this book, I'd argue, are a better complement to the empirical turn in economics, which has been driven by massive datasets and a focus on robust experimental methods, than either the abstract theorems of microeconomic theory or the perfect competition lens of price theory, and help get us closer to the real world.

This book is available through Open Book Publishers for free online and for purchase as a printed textbook. It was supported by the Emergent Political Economies Grant from the Omidyar Network to the Santa Fe Institute. 📖

Bowles and Weikai Chen, a professor of economics at Renmin University of China, present problem sets, exam questions, and detailed solutions based on a new approach to microeconomics. *Allocation, Distribution, and Policy* is an entry into a long-standing effort to build a new paradigm in economics. This book of Ph.D.-level problems in microeconomics elicits, in this reader, echoes of two ongoing long trends. One of these is the evolution of microeconomics as a discipline: the original *Notes and Problems in Microeconomic Theory*, by Bowles and Kendrick, was a tour of constrained optimization, applied to a variety of extremely stylized market situations. The

An Introduction to Ergodicity Economics



An Introduction to Ergodicity Economics (London Mathematical Laboratory, June 2025) is a new textbook that draws on physics to re-examine traditional economic theory. It begins with flipping a coin. And a

hypothetical gambit. Imagine you were offered the following: Every time the coin lands on heads, your wealth increases by 50%. And every time tails comes up, your wealth drops by 40%. Should you accept?

It depends on how you look at the predicted outcomes of this random system, says SFI Professor Ole Peters, a physicist at the London Mathematical Laboratory, who co-wrote the textbook with Alexander Adamou, a former LML colleague.

One way to characterize how your wealth will change in the coin-flip scenario, says Peters, is to follow an individual's progress over time and average the value. This is the *time average*. A different way is to calculate the *expected value*, which means calculating the average wealth of many systems at one time (say, 100 flips into the future).

These may not yield the same results: When randomness drives outcomes, expected value can rise even as the time average for an individual plummets. Peters likens this to a relatable, real-world phenomenon. “A government may say, Isn't the economy doing great? And the individual worker says, I don't really see that in my paycheck,” he says.

The tension between the time average and expected value forms the basis for a theory of ergodicity economics, which Peters has been developing for nearly 20 years. The term ergodicity describes what happens when the time average and expected value align, which means one is replaceable with the other, and the behavior of an individual system can be modeled by the average behavior of a collective. Austrian physicist Ludwig Boltzmann first introduced this concept in the 1870s, in the context of thermodynamics, to describe a physical system.

But ergodicity is a special case, Peters argues, and there's no reason to assume that the two will uniformly agree. Many systems, especially in economics, may be non-ergodic — like Peters' coin flip-for-wealth-or-poverty example. Broadly, says Peters, there is a longstanding

tension in economics between a dominant framework around expected-utility theory, with roots in the 18th century, and modern challenges to this framework that question human rationality (or even the use of formal models) in describing economic processes. Ergodicity economics offers a third way.

As a physicist, Peters had previously studied statistical mechanics, an area focused on how lots of tiny particles, moving randomly, give rise to predictable, observable behaviors. But starting around 2006, he began to find ways to use those ideas to re-examine long-held ideas in economics, particularly around how people make decisions.

He found that economic models often assume ergodicity as a starting point. For *An Introduction to Ergodicity Economics*, the first textbook in the field, Peters and Adamou present a formal challenge to that assumption, using mathematical rigor and careful examples to show how non-ergodicity can arise naturally, and how it can be addressed in models.

“We have this radically different starting point. We break this formal assumption and start new, but just as formally,” he says. “My hope is that the book will help people see this other perspective, because without it, I fear that economics is not succeeding in solving our most pressing problems.” 📖

Runnin' Down a Dream: How to Thrive in a Career You Actually Love

“Life is a use-it-or-lose-it proposition. Shouldn't you spend it doing something you love?” This is the premise of SFI Trustee Bill Gurley's new book *Runnin' Down a Dream*, a guide to pursuing a successful and meaningful career.

Gurley, now a general partner at venture-capital firm Benchmark, begins with his own experience of landing the “perfect” job out of college — a job that left him surprisingly bored — and deciding to navigate a different, uncharted path. Many people never find the kind of satisfaction Gurley has discovered in his work, but it doesn't have to be that way.

For more than a decade, Gurley has explored the themes that undergird the careers of many people who are both successful and satisfied in their careers. In his book, he digs into six core principles:

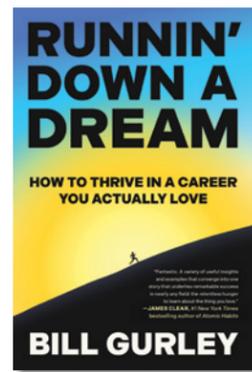
1. Chase your curiosity.
2. Hone your craft.
3. Develop mentors in your field.
4. Embrace your peers.
5. Go where the action is.
6. Always give back.

Runnin' Down a Dream builds on a 2018 talk that Gurley presented at the McCombs School of Business at the University of Texas at Austin.

Life is a use-it-or-lose-it proposition. Shouldn't you spend it doing something you love?

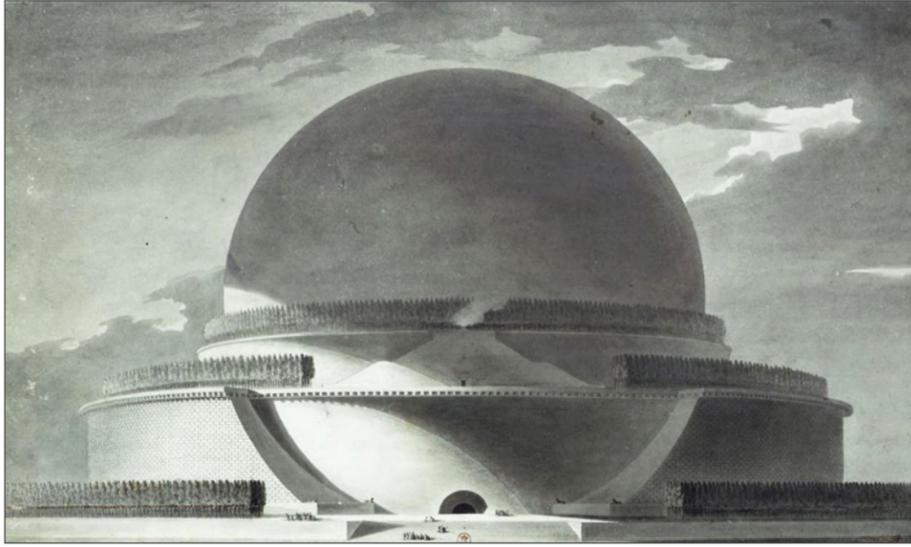
“While many readers may already be in their ‘dream jobs,’ we have found that the book really resonated with parents and other people who are sought after as mentors in career decisionmaking,” says Gurley.

Runnin' Down a Dream offers inspiration for a new generation seeking their place in the world, while offering a much-needed rebuttal to the idea that hustle and happiness are incompatible. The book, published through Penguin Random House, will be available on February 24, 2026. 📖



SFI launches Synthetic Imagination series

Written by SFI Research Fellow Anthony Eagan



"Exterior of Newton's Cenotaph." Unrealized design proposal by Étienne-Louis Boullée. 1784. Via Library of Congress.

Since the origins of modern philosophy and poetry, "imagination" has been a technical term for the human ability to cognize in images and thought combinations that reconfigure our memories or immediate experience. Gaston Bachelard puts this well in his book *Air and Dreams* when he writes, "We always think of the imagination as the faculty that

forms images. On the contrary, it deforms what we perceive; it is, above all, the faculty that frees us from immediate images and changes them." The imagination, then, allows us to conceive of new ideas, concepts, shapes, formulae, and compositions (rather than merely navigating what we perceive empirically).

FRANCIS SPUFFORD (cont. from page 2)

struggling economy fly. Meanwhile, sixty pages of notes at the back indicate that the narrative is buttressed with more research than you're likely to find in a popular history.

Spufford confronts the limitations of the novel's form in his first completely fictional effort, *Golden Hill*, putting doubts about the veracity of the narrative in the words of its hidden narrator, Tabitha. "Well, I still hate novels," she writes, in an afterward that reveals that all a reader has encountered in *Golden Hill* is the product of her character's literary imagination: "They still seem to me to be tissues of exaggeration, simplification, a sweetness that falsifies . . . How can such farragos be trusted?"

"I'm a wholehearted lover of novels, and epistemologically skeptical of them," says Spufford. "I keep meaning to return to nonfiction, and it keeps getting bumped forward as each next idea turns out to be a novel rather than a nonfiction book."

Spufford's forthcoming novel, *Nonesuch*, concerns espionage, magic ritual, and time travel in the context of WWII London. "The genuinely strange and unearthly qualities of the blitz; winding streets with all the lights out, this pitch-black fairy forest, while strangers are overhead, trying to kill you," he says. "As with New York in *Golden Hill*, I like to take cities — which are fascinating — and bring into focus elements beyond their stereotyped versions."

Histories that use the form of novels, and novels that proclaim their own limitations — Spufford's body of work keenly interrogates the categorical limits of non-fiction and fiction, utilizing tools of each mode to create a form that feels more grounded than most fiction and which can be more legible and emotionally affecting than most science writing. His spiraling and transdisciplinary meditations on history, fiction, economics, and ethics deeply resonate with the work of SFI.

Before his appointment as a Miller Scholar, Spufford attended a 2024 working group at SFI called "The Calculated Economy in the Era of Machine Learning." Organized by Johns Hopkins political scientist Henry Farrell and SFI External Professor Cosma Shalizi (Carnegie Mellon University), the working group investigated whether contemporary advancements in AI have now made achievable the kind of economic planning Soviet scientists were attempting back in the mid-century — the theme of Spufford's *Red Plenty*. The result, according to Spufford at a community lecture he gave with Farrell at Santa Fe's Lencic Theater — "Comrades: Let's Optimize" — was "a resounding maybe." Spufford remains deeply skeptical about the potential of AI in bringing about a general prosperity.

"We're all skeptics here," says Krakauer. "Or we try to be; to make bold conjectures and meet them with ruthless refutation."

As part of his Miller Scholarship, Spufford is planning a months-long residency at SFI later this year. What bold ideas — refuted or not — will emerge as heroes in the pages of Spufford's upcoming works? "I plan to be promiscuously interested in whatever I can wrap my head around," Spufford says. "SFI is so gloriously nondirective towards its Miller Scholars, and I am confident that I will find my way into fascinating conversations." 📖

BEYOND BORDERS (cont. from page 2)

but the implied second-class status hardly does them justice. One could transform the half-empty glass into a half-full one by reversing their prioritization: allow that some form of natural selection subsumes the second law (less likely) or that game theory subsumes optimization (more likely).

In her book-length essay on translation, *This Little Art* (2017), Kate Briggs describes with admiration the super-heroic efforts of a translator of Gustav Flaubert's *Bouvard et Pécuchet* — for my money one of the three best treatises on stupidity in print — who replicated Flaubert's research for the book by reading its 1,500 source texts. Briggs suggests it might have been even better to read them in the same sequence as Flaubert. Her point is that a great translation needs to wrestle with Flaubert's semantic dark matter since these ideas are only implied by the

written text but present to some degree in the minds of his contemporary readers.

In *Fifty Sounds* (2021), Polly Barton's hilarious and exhausting autobiography of learning Japanese in her twenties, the author expresses bafflement at the violation of rules implied by translating "cheeseburger" as "cheese in Hamburg." Barton explains this disregard for the semantic dark matter of the West as one requiring "considerable largeness of spirit to accept the way that these imported words were wielded with little consideration for their original usage and belonged to an utterly different web of associations to those they had in English."

In his collection of profiles, *Personal Impressions* (1980), in a chapter on "Meeting with Russian Writers," Isaiah Berlin describes the flowering of experimentalism in Russia in the late 19th century, including the futurism, supremacism,

It was with this in mind, along with the idea that the imagination may be the faculty that most distinguishes us from so-called alien intelligences (AI included), that SFI Director of Experimental Projects Caitlin McShea and I conceived of and hosted Synthetic Imagination, a small multi-day symposia series, in SFI's new Gurley Forum this past September. Given our belief that the imagination spans all human practices and provides the means for growth and innovation, we invited a variety of professionals who implement the imagination to wonderful effect.

The range of possible contributors being so vast, we limited the inquiry to architecture, urban design, and other "species of spaces" that both result from and foster the imagination, with the aim of making the event the first in an ongoing series devoted to investigating how the imagination operates. Just what is imagination, and how is it relevant to our particular endeavors — in this case the art and technique of building?

We inaugurated the series with architecture because well-designed human structures present a rich, inhabitable synthesis between the creative and constructive faculties. Each structure tends to replicate its mental origin and endow it with greater permanence and plastic

possibility, and, in this sense, the poetics of space and the space of poetics may illuminate one another.

Opening with a screening of *Nest* (Hlynur Pálmason, 2022) — a short film about three siblings who slowly build, modify, and play in a treehouse — we continued with a presentation by book-architect and artist Keri Schroeder and my own talk about bridges. Ensuing days included contributions by urban designer Jorge Almazan ("Design Fieldwork in Architecture"), photographer Kate Joyce ("Photography as Theft of the Imagination"), winemaker Abe Schoener ("Roles of the Imagination in Thinking about Vineyards"), novelist and SFI Miller Scholar Tom McCarthy ("The Threshold and the Ledger"), and SFI President David Krakauer ("Secret Histories of the Nomological Imagination"). The private event concluded with cocktails and a book fair.

McShea was excited to activate newly imagined, now actualized, spaces across the Miller Campus in novel experimental ways, using Gurley Forum as a theater and establishing an art gallery featuring Kate Joyce's photography. As she put it, "Miller Campus embodied the actual subject matter of Synthetic Imagination." 📖

SCIENCE OF STORIES (cont. from page 1)

Zhang co-organized the working group with Dodds, alongside novelist and University of Toronto marketing professor Samsun Knight, and University of Vermont computer scientist Juniper Lovato.

Participants at the working group hoped to devise methods for mapping story plots. They wanted to create visual representations of how characters, environment, and events form networks over time, and capture the flavors of interaction between characters. Another goal was to develop a rich common dataset of stories that researchers can experiment with to identify fundamental story features.

"How do we take 100,000 stories, computationally turn them into temporal networks of characters, and then have a whole bunch of species to look at?" explains Dodds.

A data-driven understanding will help address the many applications of stories — positive and negative. After all, stories do far more than entertain. Consider propaganda about kings or states that establishes a national narrative, viral stories that captivate the globe, marketing that drives sales, and conspiracy theories.

"Stories are storehouses of knowledge, but they are also instruments of power," says Dodds. "Fictional characters matter because real character matters. By using data to develop a science of stories, we can best identify and account for the power of stories in the real world." 📖

HUMAN RIGHTS (cont. from page 1)

societies. The workshop focused on long-term trends over one or more centuries, not short-term fluctuations around those trends. Accordingly, the second goal of the working group was to use the data sets to infer what features of a society might support long-term expansions of rights, and what features might lead to long-term reversals. Wealth per capita, political stability, cultural norms, and other factors have all been proposed as possibilities, but none has been subject to rigorous analysis.

The third goal was to build on the first two goals and begin developing mathematical theories for what leads rights to expand or contract over long timescales, and to test those theories against specific historical periods. By bringing together researchers from history, sociology, political science, statistics, applied mathematics, and complex systems, the organizers hoped to create shared concepts and a foundation for future work.

Through this mix of empirical testing, conceptual framing, and interdisciplinary dialogue, the group aimed to clarify one intriguing and vexing question in the study of human rights: why these shifts happened in the places and at the times they did, and how they reflect deeper principles of social change. "We know that human rights is a multifaceted, complex phenomenon," says Zhang. "The question is whether we can understand it more simply." 📖

constructivism, Acmeism, and cubo-futurism movements, followed by its suppression under Marxist ideology as "unbridled individualistic literary license." Subsequent to the German invasion, this censorship inverted: "An astonishing phenomenon took place: poets whose writing had been regarded with disfavor by the authorities and who had consequently been published rarely and in very limited editions, began to receive letters from soldiers at the fronts." The semantic dark matter of war completely reversed the reception and meaning of artistic expression.

Scientific theories and the meaning of artistic work are always modulated through a complicated system of connections — what Gilles Deleuze and Félix Guattari described as a "rhizome." This rhizome is not a "social construction" but a spanning feature of reality that is

often too complex to subsume within a single framework. It becomes a constituent of the semantic dark matter of all ideas, and it makes translation challenging. Artificial intelligence, artificial general intelligence, artificial superintelligence, ad nauseam, are all slices through epistemic networks that are made sensible only by revealing their semantic dark matter. Various Turing tests and benchmarks are little context-probes designed to reveal the historical contingency of their behavior. When we say that a large language model is only as good as its training data, we are, in effect, trying to translate from the past into the present and urging caution for why this might fail. I note that this is an effort at translation that Thomas Kuhn described as finally incommensurable.

— David Krakauer
President, Santa Fe Institute

ACHIEVEMENTS

In October, SFI Professor **Melanie Mitchell** received a 2025 Eric and Wendy Schmidt Award for Excellence in Science Communications from the National Academies of Sciences, Engineering, and Medicine.

SFI Professor **Chris Kempes** accepted an Outstanding Publication of 2024 award from the International Society for Artificial Life, held in October, on behalf of a large SFI-affiliated research team, led by SFI External Professor **Ricard Solé**, which published “Fundamental constraints to the logic of living systems,” in *Interface Focus*.

In December, SFI External Professors **Amy Bogaard**, **Tim Kohler**, and **Scott Ortman** received an award from the Shanghai Archaeology Forum for their ongoing project “The Global Dynamics of Inequality over the Long Term.”

Also in December, External Professor **Wendy Carlin** was appointed Dame Commander of the Order of the British Empire — among the highest honors in the British system — in the 2026 New Year Honours. She is recognized for her wide-ranging research in economics and for launching CORE Econ with SFI Professor Sam Bowles in 2013. The open-source curriculum now reaches roughly 165,000 students each year across more than 500 universities worldwide. 🌍



Melanie Mitchell



Chris Kempes



Ricard Solé



Amy Bogaard



Tim Kohler



Scott Ortman



Wendy Carlin

RESEARCH NEWS BRIEFS



Beaks of black-eyed juncos on the UCLA campus changed shape during the pandemic lockdowns, a new study finds. (image: Matt Bangon/Unsplash+)

THE SURPRISING IMPACT OF COVID-19 ON URBAN BIRD BEAKS

During the COVID-19 pandemic, biologists at UCLA documented a natural experiment as it played out among a population of dark-eyed juncos in Los Angeles. The pandemic lockdowns offered a rare chance to study the impacts of human activity on urban wildlife, and one impact on local juncos was a rapid change in beak morphology. In a recent paper in *PNAS*, SFI External Professor Pamela Yeh and co-author Eleanor Diamant describe how, in the first two years of the pandemic, juncos’ bills began to grow longer and more slender — more like those of their forest-dwelling kin whose beaks are adapted to foraging for seeds. As the UCLA campus reopened, the urban juncos’ beaks returned to their pre-pandemic, urban-adapted shape — shorter, stouter, and suited to scavenging for human food scraps.

During this anthropause, which saw a seven-fold decrease in human activity across the UCLA campus in the autumn of 2021 compared with the campus reopening in autumn 2022, aligned with minimal dining options and a reduction in food waste across campus. “All birds that hatched in 2020 and 2021 experienced low human activity in their early life,” the authors write. “As such, we can isolate immediate and cumulative impacts of lower human activity — including food waste — on the junco population’s morphological response.” The surprising findings highlight the substantial and inadvertent impact we humans have on other species around us.

Read the paper “Rapid morphological change in an urban bird due to COVID-19 restrictions” in *PNAS* (December 15, 2025). doi: 10.1073/pnas.2520996122

ENCAPSULATING LIFE — ON EARTH AND BEYOND

A cell is fundamentally a container — a vessel that encapsulates life at the most basic level. Many biologists believe encapsulation of chemicals may have been necessary for evolution to gain traction. But how does encapsulation occur? Is it achieved easily — or is it elusive? SFI Professor Chris Kempes and colleagues investigate crucial aspects of this process in a recent paper in a special edition of (see “How Life Begins” below) focused on the origins of life.

To explore these questions, the authors used their own existing mathematical model of a bacterial cell to examine how changing the activity of its components affects encapsulation. For example, when they slowed the speed at which ribosomes produced proteins, the cell needed more ribosomes to meet all of its protein demands. In such a scenario, these macromolecules quickly filled the cell, leaving little room for other essential components. Such a “ribosome catastrophe” would render the cell non-existent. Speeding up ribosomal activity, on the other hand, allowed the cells to grow larger and avoid the disastrous end.

Drawing on these results, the authors developed a new encapsulation model applicable to life beyond Earth or synthetic life grown in labs. The authors tested out the theoretical framework on two types of living systems: autocatalytic and genetic. Autocatalytic life consists of a network of molecules that replicate themselves. A genetic system is more complex, comprising molecules that store information coupled to those that chemically run the system.

The new model points to some principles that govern encapsulation universally. For example, if the chemical processes within a living system are slow, it can’t fit that chemistry within a container. Faster chemistry, on the other hand, allows for larger, more complex living systems that offset the loss of molecules from environmental decay and dilution.

Read the paper “How hard is it to encapsulate life? The general constraints on encapsulation,” in *Philosophical Transactions of the Royal Society B* (October 2, 2025). doi: 10.1098/rstb.2024.0297

HOW LIFE BEGINS AND WHERE IT MIGHT HAPPEN AGAIN

A recent special issue of *Philosophical Transactions B* takes on one of the biggest mysteries in science: how life first began. Instead of trying to replay Earth’s exact history, the issue’s authors look for the universal rules that might make life possible anywhere in the cosmos — the right mix of energy, chemistry, and information.

The collection of papers, compiled and edited by SFI External Professor Ricard Solé, SFI Professor Chris Kempes, and Susan Stepney, a professor at the University of York, explores that question from many angles. Some focus on the first protocells, the tiny, bubble-like structures that may have served as life’s earliest containers. Others look at phase transitions — the same kind of sudden shifts that turn water to ice — to explain how simple molecules could have crossed thresholds into organized, living systems.

Some contributors draw on thermodynamics and evolutionary dynamics to calculate how early chemical systems might have organized themselves, and on synthetic biology experiments that recreate pieces of that process in the lab. Even AI is starting to play a role, not by replacing scientists, Solé and Kempes note, but by helping explore the enormous space of chemical possibilities. The ultimate goal, they say, is to connect theory and experiment tightly enough to move the field forward.

Read the special issue “Origins of life: the possible and the actual” in *Philosophical Transactions B* (October 2, 2025). <https://royalsocietypublishing.org/toc/rstb/2025/380/1936>

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WINTER 2025 – 2026

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