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Parallax

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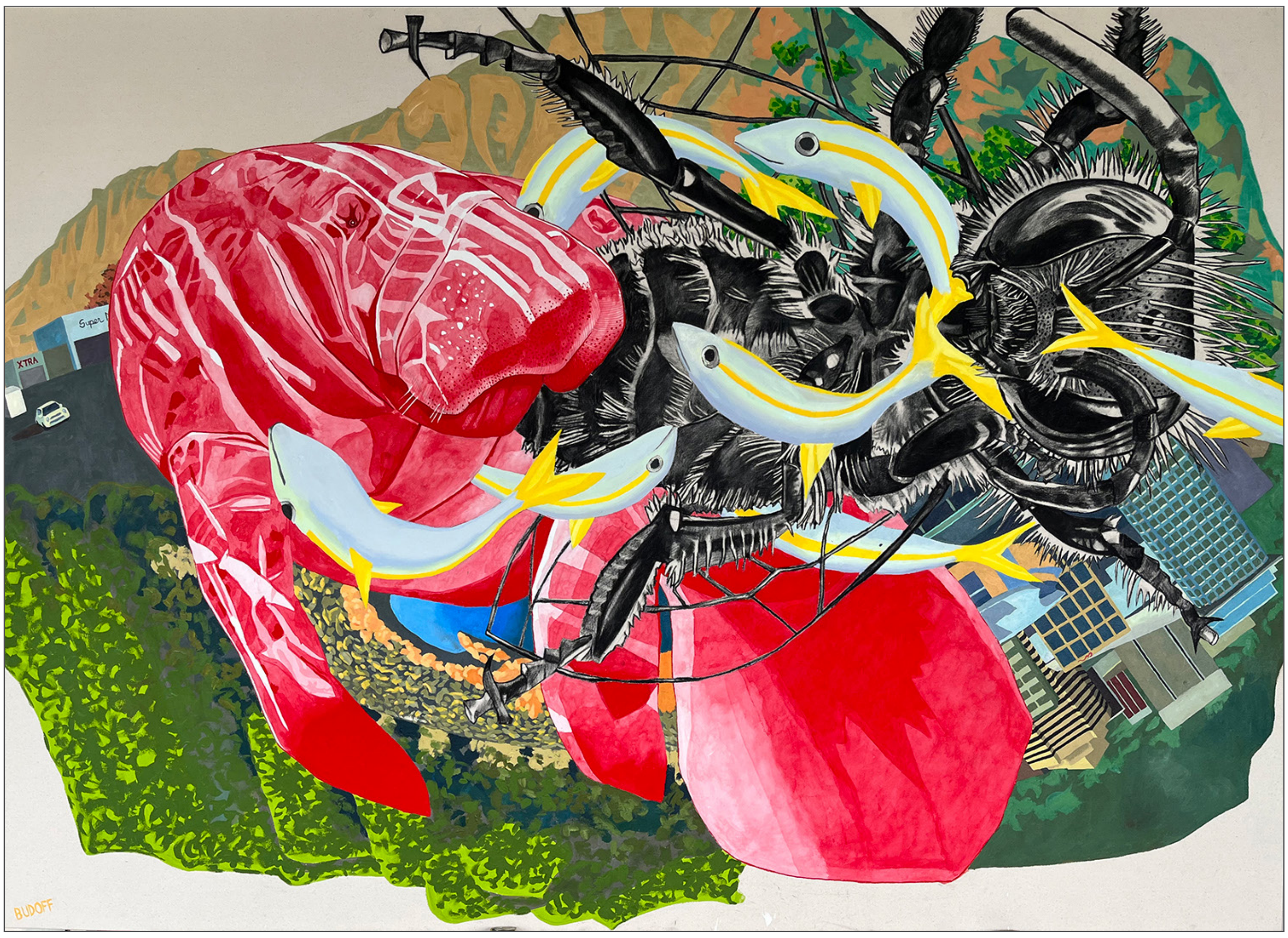

"El Abrazo" (the Embrace), 2023. Nathan Budoff. Shellac ink, charcoal, oil, and acrylic on canvas. 58" x 80." Courtesy of the artist.

Decoding animal minds

In the 1970s, Thomas Nagel famously asked, "What is it like to be a bat?" Today, large language models clamor to give an answer. Researchers optimistically argue that AI will allow humans to speak to whales, monkeys, even bats within a handful of years.

However, interspecies communications experts have pointed out major flaws in such bold claims. To explore the historical, philosophical, and empirical parameters of communicating between species, SFI co-organized the working group "Interspecies: Decoding, Translation, and Interpretation" in collaboration with the Interspecies Internet. Held at SFI May 4–6, 2026, the event expanded on a previous meeting about animals in translation.

Participants discussed what it means to "decode" communication, extracting meaning from deep databases of complex, imperfect data. They reviewed case studies: octopi experiencing something akin to nightmares, researchers playing sounds to divert a whale from a danger zone, apes communicating through gesture, Yellowstone wolves holding complex social relationships.

"The field has focused on figuring out nuts and bolts: what does a chimpanzee or a killer whale or a nightingale have in their communicative toolkit to find a mate, food, somewhere to sleep? But that's probably the least interesting part of what we humans do with our communication, and it might be the least interesting part of what these other animals do," says working-group participant Cat Hobaiter, a professor of origins of mind at the University of St Andrews who researches great-ape communication.

Participants considered how behaviors like song or social interactions illuminate possible creativity or cultural differences in other species. Decoding communication could help solve the

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SFI Professors advise judges on AI

Artificial intelligence has permeated most aspects of society, and the legal system is no exception. Today, every step of criminal justice, from the police investigation to the trial, can — and often does — involve AI. That change comes with many implications, some of them desirable and some less so.

In June, three SFI Faculty — Resident Professors Cristopher Moore and Melanie Mitchell (the James B. Alley, Jr. Professor at SFI), and External Professor Melanie Moses, a Distinguished Professor of Computer Science from the University of New Mexico — addressed these implications during panel discussions at the National Judicial Summit on the Foundation and Future of the Judiciary, held in Santa Fe. Around 300 judges attended the summit, with two-thirds of the participants coming from New Mexico. The additional hundred judges represented 22 different states and eight tribal nations.

Two guests of SFI also participated in the panel discussions: Berkeley law professor Andrea Roth and Maryland public defender Marc Canellas. Both are experts on AI-generated evidence who also attended a 2025 SFI working group on AI and Justice supported by the Robert Wood Johnson Foundation through SFI's Emergent Engineering project.

The professors' goal was to give judges a realistic view of how AI can expedite their work while also warning them of pitfalls they might encounter. "If judges and juries are dazzled by the technology, it's going to be hard for them to think critically about the evidence," says Moore. "I want people to understand that AI has strengths, and it has weaknesses."

For example, AI has made facial-recognition technology much more effective. But when using this technology, police need to balance the need to catch criminals with the expectation of privacy. "Do we want cameras on every

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Reinventing democracy before it breaks

The fledgling democracy under the German Weimar Republic after World War I soon collapsed into Nazi authoritarianism. Mid-20th-century scholars foretold that something like the fall of the Weimar Republic could happen again: the psychological tendencies underpinning a liberal and democratic culture could erode enough to topple society.

Now, many fear that a "Weimar moment" may be around the corner in the U.S.

"As long as Americans feel left out of the major decisions that are altering their lives, democracy will be in danger in this country. It's not just about redistributing income or wealth. It's about redistributing power. If we don't do that, I think we're running the risk of losing our democracy," says SFI Resident Professor Sam Bowles.

"It is true that wealth inequality leads to polarization, which destabilizes liberal democracy," explains SFI Complexity Postdoctoral Fellow Katrin Schmelz, who is also a professor at the Technical University of Denmark. But how we interact in our daily life with economic institutions — in our jobs, for example — also matters. This shapes how we evolve as citizens, and how a democratic culture may evolve."

Bowles and Schmelz co-organized a working group at SFI March 2–4, 2026, to tackle a sweeping question: "Is Liberal Democracy Sustainable?" The discussion focused largely on the role of economic institutions. At the working group, participants examined the formation (or erosion) of liberal-democratic values as a complex system that evolves over time, with dynamic interactions between actors. Discussion topics included how parents who follow orders at their jobs are more likely to want to raise obedient children (rather than independent and autonomous children), and how the history of Athens illuminates a common pattern: democracy, followed by authoritarianism, followed by reinvented democracy.

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SFI Postdoctoral Fellow Katrin Schmelz (right) with her family and neighbors at Point Alpha, the observation post that separated her home village of Geisa in East Germany, from West Germany, on the day the gate opened in December, 1989. (image: Bernhard Schmelz)

BEYOND BORDERS

SIZING UP THE GHOSTS IN THE MACHINES

All of science is in the business of exorcism. When philosopher Gilbert Ryle coined "the ghost in the machine" in *The Concept of Mind* (1949), he was identifying an unnecessary explanatory entity in Cartesian dualism and expelling it. Descartes had posited a *res cogitans*, a thinking substance categorically distinct from the mechanical body. Ryle diagnosed this as a "category mistake," and explained it away in the manner an Oxford professor does any superstition: like being shown the colleges, library, and playing fields of the university, and still asking the benighted question, "But where is the University?"

What Ryle did for mind, other sciences have done for their own spectral inhabitants. But the ghosts differ in kind, and so do their rites of exorcism. Physics exorcises supernumerary particles — unnecessary free parameters in pursuit of universality. Biology exorcises redundant processes — divine or teleological agencies. And the sciences of intelligence exercise imposed patterns — transcendent sources of cognition. Each tradition seeks minimality, yet each means something profoundly different by it.

The deepest ambition of physics has always been to reduce the number of independent facts the universe requires us to accept. Theoretical physicist Eugene Wigner observed that symmetry and invariance principles act as filters on possible theories, eliminating free parameters with a scandalous efficiency. And Einstein's general relativity derived gravitation from the minimal geometric postulate that spacetime curvature is gravity, eliminating Newton's action-at-a-distance.

Biology's ghost was never a free parameter but an agent. Before Darwin, the complexity of organisms demanded an intelligent designer the way a watch implied a watchmaker. *On the Origin of Species* (1859) performed an exorcism on the demiurge itself and replaced a transcendent creative process with a mechanical one. The ghost to be exorcised is the unnecessary rule, an act of God or Lamarckian inheritance. What remains after exorcism is not the universal parameterization of physics, but a universal mechanism (selection) that operates locally and iteratively.

Alan Turing showed in 1936 that a device of absurd simplicity consisting of a tape, a head, and a finite set of states could compute anything computable. Warren McCulloch and Walter Pitts demonstrated in 1943 that networks of binary threshold neurons could instantiate logical operations. Both of these exorcisms expelled patterns of architectural extravagance that Descartes and his followers had imposed on the mind. David Marr, in his 1969 model of cerebellar cortex, proposed a single, repeating architecture consisting of Purkinje cells trained by climbing-fiber error signals, that could learn arbitrary input–output mappings. Computation of

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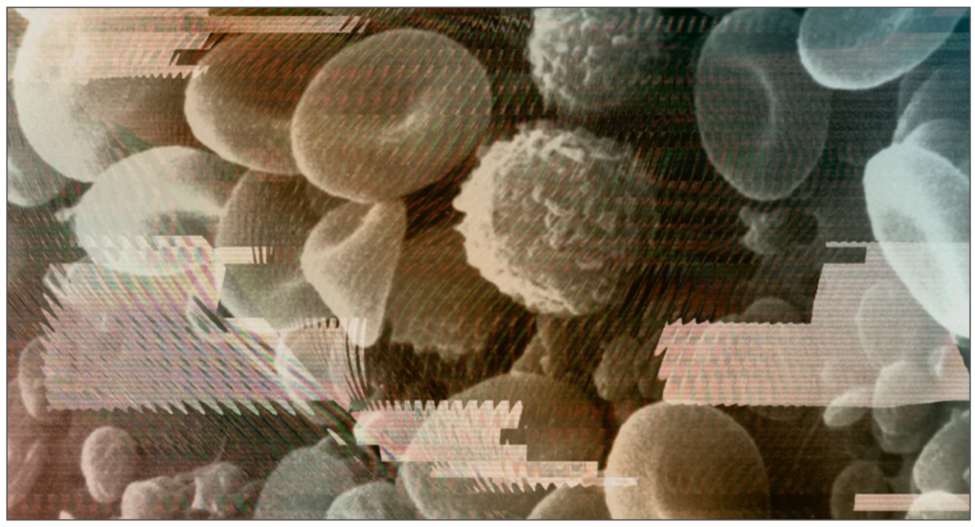
Noise may be key to understanding cell group patterns



Noise abounds in nature, and deterministic models often fail to account fully for its influence. (image: Unsplash)

All of biology is transient. Over time, a population of identical cells can change so that some subgroups exhibit different behaviors — everything from varying sizes to the expression of certain proteins, or regulation of processes like metabolism.

Cell biologists have long assumed that these population-scale behaviors are determined by individual-level mechanisms, and that observations of these subgroups can reveal what happens at the single-cell level.

SFI Postdoctoral Fellow James Holehouse says it's time to challenge that assumption. In a recent paper in *Proceedings of the Royal Society B*, Holehouse describes real-world counterexamples in which population-level cellular patterns don't correspond to individual behaviors. "This is a complete breakdown of those previous assumptions," he says. "What we see on the population level is not reflected if you look at the trajectories of individuals in that population."

If researchers want a better understanding of how collective behaviors emerge, he says, they should consider the interplay between transience and randomness more seriously. Holehouse, a mathematical biologist, has long studied the role of noise, or randomness, in cellular processes like metabolism and how cells produce the right number and balance of proteins. And what he's found is that the behavior of the collective can't be entirely explained by tracing the deterministic changes in individual cells, or in the steady states of populations of randomly varying cells.

Holehouse looked at specific cases where conventional models of cell biology — those based on the idea that individuals should determine group patterns — would predict only a single possible mode. But in the new paper, he shows how transient, time-dependent effects, a fundamental property of biological systems, can lead to two distinct modes, or subpopulations of cells, in a population of identical cells that only appear equipped to produce a single mode. Two distinct modes can emerge if a model takes stochasticity, or random noise, into account.

In the past, says Holehouse, researchers relied primarily on deterministic models and treated noise as a kind of disturbance to those solutions. But noise is everywhere in nature, and deterministic models often fail to account fully for its influence. That omission, he says, could inhibit the ability of models to predict fully how cellular systems use regulatory systems that become more or less important over time. A cell subject to extreme heat, for example, activates survival pathways as a transient — or temporary — response.

"Understanding the novel behaviors that come about through stochastic processes interacting in a time-dependent setting," he says, "tells us something very, very important about regulation in transient settings. It gives rise to an entirely new space of novel biological behaviors." Holehouse is continuing to develop his approach, identifying which processes produce the phenomenon of transient bimodality described in the new paper. "These types of phenomena have some very non-intuitive ways of realizing themselves," he says. "It's important that we understand the many origins of cellular differentiation, and that biological mechanisms get attributed to the correct qualitative explanations."

AGI through the lens of natural intelligence

Human intelligence involves many dimensions: we interact socially, learn quickly from other people, and determine how tasks fit together, as well as physically interact with and intervene in the real world.

"The way cognitive scientists think about intelligence is much broader than just solving tasks," says SFI James B. Alley, Jr., Professor Melanie Mitchell. In contrast, AI companies define intelligence as decomposable into small tasks, accounting for only a sliver of the full range of natural ability.

That narrow definition is an issue in light of AI companies' prevailing narrative that "human innovation — which got us to the moon, which has given us antibiotics and *Middlemarch* — will be done just as well by AI," says SFI External Professor John Krakauer, a professor of neurology and neuroscience at the Johns Hopkins University School of Medicine.

To explore this disconnect, Mitchell and Krakauer convened an SFI working group, "The Nature of Intelligence: Cognitive Science Perspectives on AGI," on March 31–April 2. It was the third of six in-person meetings of leaders on the Nature of Intelligence, a project supported by a gift from the Wicklow Foundation.

The participants, who have expertise in fields such as neuroscience, psychology, philosophy, and artificial intelligence, are all investigating the nature of intelligence, whether in biological systems or machines.

The working group explored the idea of artificial general intelligence from the perspective of cognitive science. The concept of AGI lacks an established, agreed-upon definition, which will make it difficult to know if and when it is ever achieved. AI companies track performance on benchmarks based on human achievements, some of which derive from the logic of IQ tests.

In contrast, cognitive science avoids an overarching definition of intelligence in favor of comparative experiments. Objective, quantitative measures of intelligence, such as IQ, have been disfavored as accounting for just a portion of natural abilities.

The group set out to explore the definitions of AGI proposed by AI companies, whether those definitions were coherent, and the extent to which they overlap with how cognitive scientists think about intelligence.

While they sound impressive, benchmark-based achievements often don't hold up in the real world, Mitchell says. Krakauer notes that open-ended, curiosity-driven activities such as art and science are particularly difficult to reduce to task-based problem solving.

Other themes the group explored include the link between language and intelligence and the existential threats that AI poses, ranging from near-term threats such as disinformation to speculative threats, such as AI systems developing their own desires and goals.

While they disagreed on some points, Mitchell says, "we agreed that the conception of intelligence that comes out in many discussions of AGI is not one that people who study natural intelligence necessarily focus on."

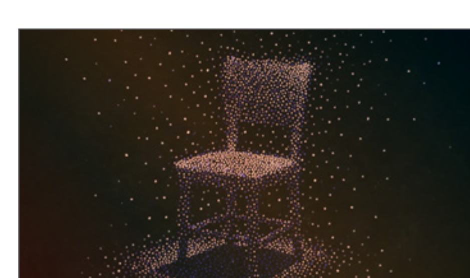
How do deep-learning models process 3D shapes?

A chair can still look like a chair even when its surface is reduced to a sparse cloud of points. Humans are remarkably good at recognizing objects from this kind of minimal 3D information, but a new study by SFI Program Postdoctoral Fellow Shuhao Fu and co-authors asks whether deep-learning models represent 3D shapes in ways similar to human vision, or arrive at object recognition by different means.

The study compares human observers with two leading models for point-cloud recognition: the convolution-based Dynamic Graph Convolutional Neural Network, or DGCNN, and the transformer-based Point Transformer. Across three experiments, the researchers made recognition harder by reducing point density, distorting local geometric structure, and scrambling object parts. Human performance remained strong when point clouds became sparse or when local geometry was altered, but dropped sharply when part configuration was disrupted. That pattern suggests that human 3D-vision depends strongly on global shape and the spatial arrangement of parts.

Among the models, the Point Transformer more closely matched human performance. To understand why, the authors conducted ablation studies, systematically removing parts of the model to see which ones mattered most for this human-like behavior. They found that the key was hierarchical downsampling, which lets the model build increasingly abstract shape representations across layers. Removing that module reduced human-like performance, while adding it to DGCNN improved it.

"Hierarchical abstraction was the critical factor identified in the ablation tests," Fu says. "It encourages the model to integrate information across the entire shape, leading to more robust and human-like behavior." The finding suggests a promising direction for future AI models that need to recognize 3D objects more robustly.



A study in PLOS Computational Biology *asks whether modern deep-learning models rely on the same kind of shape representations as humans, or achieve recognition in different ways. (image: Partially AI-generated & hand-edited by Edson de la O)*

In Memoriam: Jim Rutt, SFI Trustee Emeritus

Jim Rutt, SFI Trustee Emeritus. (image: Kathleen Walker)

Jim Rutt, SFI Trustee Emeritus and Distinguished Fellow, passed away on May 27, 2026, at age 72. He is survived by his wife, Celia Culver Rutt, and daughter, Kathleen Walker.

Rutt's earliest involvement with SFI was as a Researcher in Residence in the early 2000s. From his office at SFI's Cowan campus, he explored complex adaptive systems, agent-based models, and market economies. In 2003, he joined the SFI Board of Trustees, served as Board Chair 2009–2012, and remained an active Board member until 2022.

Before becoming involved with SFI, Rutt played a key role in several major information and technology companies. Holding a business degree from MIT, Rutt was the CTO for the Canadian publishing giant Thomson Corporation, followed by a period as CEO of Network Solutions, a technology company that administered Internet domains in the .com, .net, and .org namespaces. In 2001, he negotiated the company's $15 billion acquisition by Verisign.

During that time, Rutt had been exploring complex systems. He stumbled across genetic algorithms and John Holland's book, *Adaptation in Natural and Artificial Systems*, while at Thomson Corporation, and after retiring in 2001, he took what had become his main hobby — complex adaptive systems — and began building computer agents that could play the game Othello.

By 2002, Rutt was an SFI Researcher in Residence, pairing his interest in games with his business background, working with Doyne Farmer's group simulating financial markets, and conducting research on genetic algorithms. "Jim started a weekend gaming club where we used the analysis of simple board games and video games as a means of gaining insight into complex phenomena," recalls SFI President David Krakauer, who had joined SFI's resident faculty shortly after Rutt's arrival. "This style of reasoning carried over into Jim's fascination with politics, nations, and civilizations. I see his later interest in what he called Game B as a very natural extension of this fascination with generative rule systems."

As a member of the Board, Rutt brought his deep interest in organizational structure to bear at pivotal moments for the Institute. "Jim was very caring, really understood what SFI was about. He was a maverick — spoke his mind — but was very concerned about structure and operations," says SFI Professor Geoffrey West, who served as SFI President from 2005 to 2009. "Near the beginning of my presidency, we initiated an operations review. We brought in [Board members] Gary Bengier, Elizabeth Davis, and Joy Covey, and sat down with the books. Jim really held our feet to the fire, but without a big stick. I very much appreciated it."

When the 2008 financial crisis hit, West and the Board faced difficult choices to keep the Institute afloat. "A lot of people wanted to fire postdocs and staff," recalls West. "If we made that choice, I knew it would take decades to recover. Jim and [then-Board Chair] Bill Miller were in the minority of voices who said 'preserve the science at all costs.'"

In 2009, Rutt followed Bill Miller as Chair of the Board. The Institute was still roiling from the financial crisis, and the situation looked precarious. "He had to navigate us through one of the most difficult financial periods," says SFI Trustee Michael Mauboussin, who served as Board Chair after Rutt stepped down in 2012. By the time David Krakauer returned to SFI in 2015 — this time as President — the world had largely recovered from the crisis. "Jim laid the groundwork to draw David, and did so under austerity, making good decisions when things were hard," recalls Mauboussin.

"I was very fortunate to have Jim and his wife, Celia, as friends and colleagues when I returned as President," says Krakauer. "Jim and I would talk regularly about allocation of effort. He had discovered for himself that it is far better to focus on a small number of important projects than feel compelled to disperse one's attention over numerous small projects which are very likely to do well without you. This is hard-won wisdom, and Jim was ruthless in helping me prune distractions. As a Trustee, Jim was exemplary in his commitment, first and foremost, to brilliant people and to radical and rigorous new ideas."

SFI Trustee Katherine Collins, who served as Board Chair from 2021–2025, adds, "Jim embodied all of the most essential qualities of our community — intense curiosity to surface new ideas, a finely tuned bullsh*t detector to challenge points that required it, and a perpetual good humor that gave everything the air of a joyful expedition."

Beyond his skill and interest in leadership and organizational structure, Rutt had an expansive curiosity. During his time in Santa Fe, he hosted a radio show at KSFR, a local public radio station. And later — following a move back to Virginia where he co-launched a Makerspace in the town of Staunton — he began a podcast, "The Jim Rutt Show," where he could pursue his intense curiosity and dedication to open inquiry. Since the show's first episode in July, 2019, with SFI External Professor Simon DeDeo, Rutt hosted 346 episodes.

"Jim embodied all of the most essential qualities of our community — intense curiosity to surface new ideas, a finely tuned bullsh*t detector to challenge points that required it, and a perpetual good humor that gave everything the air of a joyful expedition."

"Jim had a big presence — a booming voice, intellect, and personality — and he liked to think about very big issues," says Mauboussin. "He was a super smart guy, very engaged, not afraid to entertain wacky ideas, and always willing to talk with people from all walks of life."

"He was mischievous, iconoclastic, and a complete terror on propriety to the very end," adds Krakauer. "He kept his interests and his mind running in high gear, which is something that I think all of us would desire. Jim's life was, in many ways, exemplary and burned at a very high temperature. We shall miss the man!"

In Memoriam: Peter Schuster, SFI External Faculty Fellow

Peter Schuster, External Faculty Fellow, in 2003 at SFI. (image: Walter Fontana)

SFI External Faculty Fellow Peter Schuster, one of the world's leading theoretical chemists whose work laid the foundation for many research directions at SFI, died on June 14, 2026. He was 85. He is survived by his wife, Inge, and son, Manfred.

Based in Austria, Schuster was prominent in European scientific life, serving as the Austrian Academy of Science's Vice President 2000–2003 and President 2006–2009, and leading the Institute for Theoretical Chemistry at the University of Vienna for several decades. He was a prolific author, with nearly 400 scientific papers and 15 books to his name, and contributed as an editor to multiple journals, including *Complexity*, where he served as Editor-in-Chief 2002–2016 and contributed more than 30 essays since the journal's launch in 1995. Inge, who is also a chemist, has shared many of these on her ScienceBlog and plans to turn them into a book. "They give an easily understandable overview on Peter's work and concepts," she says.

Early in his career, Schuster was a postdoctoral fellow at the Max Planck Institute for Physical Chemistry in Göttingen, Germany, where Manfred Eigen was director. Eigen had just won a Nobel Prize in chemistry for techniques to measure extremely fast chemical reactions — techniques that would help propel the field of molecular biology. Schuster and Eigen began a collaboration that continued for years after Schuster's postdoc ended, and they "began to develop a dynamic theory of the self-organization of matter," writes Inge in her obituary for Peter.

In their 1979 book *The Hypercycle*, Eigen and Schuster expanded on Eigen's mathematical formulation of hypercycles — self-replicating molecules like RNA that are connected through self-sustaining, auto-catalytic reactions. And in 1989, Eigen, Schuster, and John McCaskill provided a rigorous and fairly complete mathematical understanding of the idea of a molecular quasi-species — a "cloud" of related, but mutated, genotypes — posing a chemical–kinetic theory for the origin of life. Hypercycles and quasi-species would become the foundation for novel ways of thinking about biological evolution, robustness, and life itself.

While Schuster's work led to new understandings of how life evolves, his ideas have themselves evolved among students he taught directly and those influenced by his work, says SFI External Professor Aviv Bergman (Albert Einstein College of Medicine). "[His students] have carried Peter's intellectual tradition into very different territories. The ideas have taken on a life of their own, mutating, traveling through generations, and finding new expression in those who inherit them."

Walter Fontana (Harvard Medical School), a former SFI Resident and later, External Professor, who met Schuster while pursuing his Ph.D. at the University of Vienna, is one of those students. The German term for a Ph.D. advisor is *Doktorvater* — essentially, doctorate father — calling to mind notions of family, and reflecting the close relationship between supervisor and student, much like a master craftsman and an apprentice. "As an academic father, Peter was not merely a professional mentor; he was also a patron, a witness, an advocate, and someone who opened doors for my academic career," says Fontana.

During a postdoctoral fellowship at Los Alamos National Laboratory in the lab of Doyne Farmer (now an SFI External Professor based at the University of Oxford) in 1989, Fontana spent significant time "down the hill" at SFI's offices, eventually pursuing a second postdoc at SFI. "It was fairly natural that I would help connect SFI to my Viennese network. Peter began visiting with some regularity, and so did [now SFI External Professor] Peter Stadler," says Fontana. In 1991, Schuster became a Researcher in Residence, and in 1992, joined SFI's External Faculty.

"Peter Schuster's take on evolution was completely different. It came not from biology, but from biophysics and biochemistry, and that opened completely new horizons."

In one of their foundational collaborations, Schuster and Fontana worked to expand on Eigen and Schuster's quasi-species theory to model a fitness landscape based on RNA folding. "This might have been the first computational model of a biophysically anchored genotype-to-phenotype map," says Fontana; their work modeled how various RNA molecules, each with one or two mutations from the others, might produce the same folded protein or catalyze the same chemical reactions. In their 1994 paper "From sequences to shapes and back: a case study in RNA secondary structures," Fontana, Schuster, Stadler, and Ivo Hofacker modeled a network of these related molecules such that any individual was separated by one or two mutations, spreading across what they called a "neutral network."

For SFI External Professor Andreas Wagner (University of Zurich), this work had profound consequences for understanding how evolution can explore a genotype space, "because it can lead to astronomical numbers of different genotypes while preserving a phenotype, and some of those genotypes might be close to novel molecules that do useful and new things." In 1993, Wagner was a Ph.D. student at Yale when he heard Fontana present this work, just before its publication. This opened a path for Wagner and others to understand how organisms may find a variety of evolutionary solutions to the same problem. "Until this point, mainstream evolutionary biology was dominated by an interpretation of the world that had been established in the 1920s. Peter Schuster's take on evolution was completely different. It came not from biology, but from biophysics and biochemistry, and that opened completely new horizons."

Schuster's work researching the origins of life from a physics-inspired minimal-model approach fit well with SFI's early work, says Stadler (University of Leipzig), who was among Schuster's Ph.D. advisees at the University of Vienna. While notions about complexity and interdisciplinary work have evolved since the early '90s — a time when complexity science was understood primarily as transferring methodology from physics onto other fields — the cross-disciplinary conversations happening in Santa Fe were nonetheless unusual in academia, says Stadler. "Being part of SFI was very important to my scientific socialization, and this goes back to what I learned from Peter — you know, 'this is not my field' is not an argument. Nature doesn't care how universities organize departments, and you have to use whatever tools are available to solve the problem you are working on."

Fontana agrees. As he sees it, Schuster's influence on SFI was an inevitability. "Peter *had* to become an important presence in the early days of SFI because of how he contributed to and fit into the prevailing paradigms," says Fontana. "The quest for understanding what complexity is about has, I believe, barely begun. Beyond the feat of solving well-posed problems, the foundations that Peter and others laid at the dawn of SFI provide a firm ground from which we can better frame the questions that lie ahead."

Upending assumptions about learning

Psychologists assume humans learn by simplifying their experiences, but might we also learn through supercharged complexity? (image: Sabina Sloman with Gemini AI)

In the last decade, a phenomenon in artificial intelligence known as "double descent" has surprised researchers who study learning. The expectation was that the best AI models were neither too simple nor too complex. But certain models (like systems that classify images) actually learn best when the model grows extremely complex, far more than the data.

Over a century of psychological research assumed this was impossible: no system, animal or artificial, should be able to learn through such a method. Given constrained resources for storing information, systems should forget most of what they experience and only hold onto key themes.

Now that there's proof of AI models successfully learning not through simplifying and forgetting, but through supercharged complexity, researchers are investigating whether humans can do something similar. A recent paper in *Brain and Behavioral Sciences* aims to spark such investigations by proposing a new framework for human learning. Each year, the journal accepts a mere dozen or so manuscripts. Then it solicits up to 40 commentaries from outside experts, and publishes the robust scientific debate.

"We are challenging a long-standing assumption that says humans can't learn complex representations and successfully generalize their knowledge," says co-author and SFI Complexity Postdoctoral Fellow Marina Dubova, a cognitive scientist. "And we are proposing a framework that can be used to test if a certain human behavior actually demonstrates excess-capacity learning."

The paper, co-authored by Sabina Sloman of the University of Manchester, defines "capacity" as how many resources a learning system, like a human or AI model, devotes to representing its experiences. There are three kinds of capacity learning: constrained (where you don't remember every experience), sufficient (where you remember every experience), and excess (where you remember every experience and supposedly irrelevant details about these experiences).

Psychological evidence already shows excess-capacity learning may exist in humans. Humans come up with more complex interpretations for phenomena than needed, and they often memorize redundant information.

Imagine you want to learn what kind of food you like. In the traditional psychological "constrained" view, you forget the details of each meal you try, only remembering that you like burgers. But one night, you have a bad burger. Excess-capacity learning means you memorize the exact details of the bad meal, and use these details to make predictions about future meals. Your predictions might depend on relevant details (the restaurant where you ate the bad burger) and details that may at first appear irrelevant (the day of the week).

Surprisingly, this excess complexity can help you make a better prediction about your next meal — while the day of the week alone may not directly affect burger quality, it could indicate which chef is working that day.

"Excess-capacity learning means that once you have memorized the exact details, you don't need to discard the specifics to generalize. Instead, by retaining and even expanding on the details, you can arrive at a representation that generalizes well, sometimes even better than simplifying would. Cognitive science hasn't fully explored this mode of learning," says Dubova.

Study analyzes publication trends at top journals

Competition for publication in the top scientific journals like *Science*, *Nature*, the *New England Journal of Medicine*, and the *American Economic Review* is fierce. Every year, elite journals like these receive tens of thousands of submissions, which go through a multi-stage peer-review process — the gold standard for assessing whether a study meets the criteria for publication. The small fraction of papers that make it to publication play a powerful role in scientific discourse, shaping both public policy and scientific careers, yet the confidentiality involved in the peer-review process limits the possibility of studying the process itself.

This lack of data means that "peer review at elite journals is both undertheorized and undercharacterized, despite many insights from past studies about peer review in general," write the authors of a recent paper that begins to take on the challenge. Examining more than 110,000 submissions to *Science* and *Science Advances* from 2016 through 2020, co-authors Sam Zhang, a former SFI Complexity Postdoctoral Fellow now at the University of Vermont with SFI External Professors Aaron Clauset and Dan Larremore (both at CU Boulder) and others, found that researchers from prestigious universities with large research teams were more likely to be published, while papers with smaller research teams, authors based in China or at lesser-known schools, or whose topics focus on social science face a disadvantage. The study, along with an anonymized dataset, was published in *Science Advances* on July 13.

"This is really a first look at this process that was previously opaque," says Zhang. "With the rise of AI slop and the ability to mass-produce junk science, the role of established gatekeepers like these elite journals becomes more important as these processes get put under strain. These types of open-data analyses about what is going on at the journal might help the community prepare for and understand how editorial processes will need to change."

. . . confidentiality involved in the peer-review process limits the possibility of studying the process itself.

The findings raise an important question: To what degree are important scientific discoveries going unnoticed because their authors lack certain characteristics? By calling out potential biases and making their dataset publicly available, the authors hope to help journals improve their processes, though they urge caution in interpreting the results.

"A crucial point about our analyses is that none of our findings rise to the level of causality, and they should not be interpreted in that way," says Clauset. "Rather, what we do find is a number of fascinating associations between certain attributes of manuscripts and their relative success in peer review at elite journals like *Science* and *Science Advances*. For instance, we find little overall association between author gender and success in peer review. What little association we do find is consistent with a seniority effect: more senior researchers are somewhat more likely to be men."

REINVENTING DEMOCRACY *(cont. from p. 1)*

For Schmelz, who was born in East Germany before the fall of the Berlin Wall, the path forward is also personal. "I grew up in an authoritarian country, so I worry deeply about what we're seeing in the world," she says. "But discovering these long historical patterns — that democracy is not an eternal fire but can transition and learn from the past — leaves me more optimistic."

Schmelz and Bowles got the idea for the working group last year, while writing a chapter for a forthcoming handbook on the subject and organizing a meeting on how climate policies and people's values coevolve.

"Our hierarchically organized economy, in which few people are exercising much autonomy, doesn't look like fertile ground for the cultivation of democratic culture. Liberal democracy may have to save itself by becoming more economically democratic, in the sense of ordinary people having a greater voice in their work and daily lives," says Bowles.

Schmelz and Bowles plan to translate lessons from the working group into a new research agenda over the next decade. Along with SFI President David Krakauer and other scholars, they also joined a public panel discussion on "Crossroads Democracy" — SFI's first 2026 Community Lecture — on April 14. A recording of the lecture is available on SFI's YouTube channel (www.youtube.com/@SFIScience).

This working group was supported under SFI's Emergent Political Economies Grant provided by the Omidyar Network.

DECODING ANIMAL MINDS *(cont. from p. 1)*

problem of other species' minds — revealing a consciousness related to, but distinct from, our own. In contrast, participants also emphasized how important it is not to overstate the progress AI models and other attempts at interspecies communication have made.

Anthropomorphism — for instance, assuming most animals primarily "speak" a "language" through vocal sounds — is an ever-present risk. "There's no simple system to crack the code of animal communication, and that's why we need multiple meetings to approach solving the problem," says working-group participant Irene Pepperberg, a research professor in Psychological and Brain Sciences at Boston University who has demonstrated the advanced communicative and cognitive abilities of grey parrots, starting with one named Alex in the 1970s.

"Looking at the original interspecies communication researchers, we're an endangered species ourselves. And nasty disagreements destroyed the field initially, so it was great at SFI to see everyone working on a path forward," says Pepperberg. Working-group organizers are planning a sequel to a particularly contentious 1980 New York interspecies communication meeting, hoping to symbolically mark a new era of collaboration in the field.

"The challenge of translating from one species to another vastly exceeds the already extraordinarily difficult problem of translating from one human language to another. This becomes doubly challenging when one considers that the content of communication is likely to be a form of social coordination and not a utilitarian description of the world," says meeting co-organizer David Krakauer, SFI President and William H. Miller Professor of Complex Systems. "The fascination of this problem is considering very new theories that go beyond the rather simple fitness-enhancing picture presented by the standard Darwinian framework. The new data make this a very exciting moment for new discoveries, and this is an almost perfect collaboration in which to pursue them."

This working group received support from the Miller Omega Program at SFI and the Interspecies Internet.

AI ADVICE TO JUDGES *(cont. from p. 1)*

street corner that are constantly watching us?" Moore asks. "That's a policy question, and I think a very important one." He also stressed that police and judges should be aware that facial recognition is far from infallible. He thinks it should be treated as an anonymous tip, as opposed to being used as grounds for arrest.

"We have a constitutional right to confront our accusers, and you can't confront a black box."

Facial recognition and other AI tools may also perpetuate biases against certain demographic groups because the content they generate reflects their training data, in which vulnerable groups are often underrepresented. Humans also perpetuate biases, however, so whether AI is more prone to this than we are is still an academic question worth studying, Moses says.

Similarly, AI expedites legal writing, but comes with the risk of hallucinations. Some lawyers and judges have been embarrassed when their briefs were found to contain fictional cases or misinterpretations of real cases. Reading AI-generated text carefully is a first step toward catching these inaccuracies, but "as these tools get better, the mistakes become more subtle and harder to spot," says Moses.

Meanwhile, the accessibility of the justice system has been remade by AI. Laypeople can now ask chatbots whether their case is worth bringing before a judge, and as a result, the number of lawsuits filed without a lawyer has jumped substantially. For example, federal courts saw a 69% increase in cases related to the Fair Housing Act filed without a lawyer in the first nine months of 2025 compared to 2024. Some of these cases are worthwhile, but other times AI, with its tendency toward sycophancy, erroneously tells users they have a good case. Moses says judges will have to adjust to how AI is shifting the nature of cases that end up in their courtrooms.

Judges who attended the sessions had a wide range of mindsets regarding AI, from enthusiastic to highly skeptical, mirroring the general population, Moore says. His hope is that the panel discussions demystified the technology and gave judges a feel for how the field of AI is evolving so that they can make informed decisions about which tools can be used responsibly in which situations.

In particular, one message Moore was sure to convey is that AI can help deliver justice, but only if the tools are designed to be transparent. Some use proprietary systems that prevent independent groups from testing them for accuracy and fairness, and that makes it hard or impossible for the defense to contest the evidence they produce. "We have a constitutional right to confront our accusers, and you can't confront a black box," says Moore.

Book Review: *Tipping Out of Trouble*

Review by External Professor Tim Kohler (Washington State University)

Some books make you larger, and some books make you small. Marten Scheffer's new book is a triumph all in all!

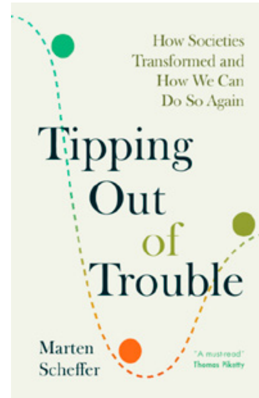
I feel no shame in channeling Grace Slick and *Alice in Wonderland*; Marten Scheffer's new book, *Tipping out of Trouble*, will open your mind to how scientific knowledge can be turned into social change to address our most dire problems.

These problems, as we well know, are fundamentally intertwined: a planetary crisis driven by ever-increasing anthropogenic CO_2 coupled to an earth-system crisis driven by our "exponentially rising human footprint;" per-capita consumption in high-income countries of some 24 tons/person/year (of extracted biomass, fossil fuels, metals, and minerals embodied in final demand) in 2020; societies riven by individualism, lack of trust in institutions, extreme (and rapidly increasing) wealth inequality, and political polarization.

And yet, starting from its title, the fundamental tone of this book is hopeful. The big question is how our global industrialized society can escape the state just described in favor of one where "humans and other species can thrive in the centuries to come." Scheffer begins by explaining how dynamical systems can rapidly change from one relatively steady state to another as one of its basins of attraction steadily shallows ("loses resilience") through slow change, to the point where small events (environmentally induced, or intentional actions) can move the system past a "tipping point" into an alternate basin representing a new and relatively stable state. Since the beginning of his career as a young limnologist, Scheffer has applied this and similar models in his earliest publications on lake eutrophication, eventually finding resonances in changes of systems as diverse as human brains at the onset of migraines, coral reefs, oceans, forests, and arid lands.

> Marten Scheffer's new book, *Tipping out of Trouble*, will open your mind to how scientific knowledge can be turned into social change to address our most dire problems.

In this book, though, as in much of his more recent work, he's most concerned with change in societies, especially the relationships between societies and their climates/ecosystems. Take smoking in public, for example: In keeping with the general model of tipping points, widespread changes in a society's norms and behaviors have happened suddenly, tipping into a new regime only after incremental pressures (say, from activists) reveal how current practice (public smoking) is at odds with a growing awareness of its ill effects. This suggests that there is hope in our various small actions (recycling, purchasing an EV) even though they may seem to lead nowhere immediately.



Two things make the tipping-point model interesting. The first is its generality, and the second is its ability to provide some metrics (e.g., high temporal autocorrelation, and slower recovery from perturbation) for how complex systems should behave shortly before a state shift. Prediction of any social phenomenon is no small feat.

I urge you to read the book to find its more specific recommendations for speeding movement towards a less stressful and more just society that respects its planetary boundaries. Scheffer is usually quite cautious in attributing causality, but I agree with the weight he places on economic inequality as a key precipitator of many of our social ills, deeply connected as well with our vast consumptive habits. Though the book has some competitors, this is the one I'll be gifting to my local congressman . . .

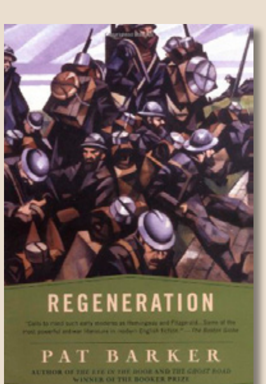
Marten Scheffer's new book towers over them all.

What we're reading — The Human Machine?

The first philosopher to put forward the machine theory of human beings, Julien Offray de La Mettrie, argued that we are not ensouled beings, but are purely material entities whose minds are functions of the body's physical processes. In *Man as Machine* (1747), his agenda was to limit philosophical and theological speculation about the soul, and to urge a more scientific, anatomical approach to the investigation of human nature. Provocatively, he concluded that only "philosophers of the human body" are able to think on these matters without prejudice.

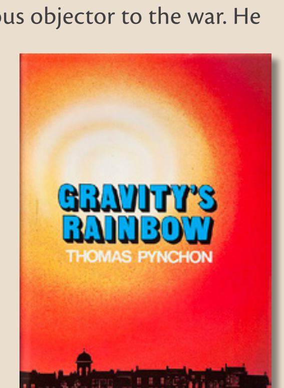
Over a century later, in *Methods and Results*, Thomas Henry Huxley suggested that human consciousness was an epiphenomenon of our soft machinery, and, borrowing from René Descartes and La Mettrie, compared us to automata. In the 20th century, Norbert Wiener famously argued that humans and machines can be understood through common principles, while John von Neumann compared brains and computers, exploring similarities between biological and artificial information-processing.

Are such descriptions to be taken literally, or has it become increasingly convenient, as we are exposed to ever more machinery, to think in man–machine analogy? To some, an even more intriguing question is not whether we are by nature machinelike, but whether governments, militaries, corporations, and even technologies increasingly transform people into machinelike components within their own larger operations. To borrow language from Karl Marx, do we become "living appendages of the machine"? And does engaging and integrating with machines make us more machinelike? Using wildly different approaches, our three books deal with some or all of these questions.



***Regeneration*, by Pat Barker**

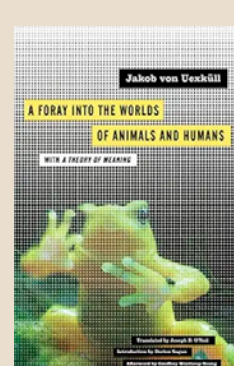
The title of this touching and disturbing WWI novel is deeply ironic. Psychiatrist William Rivers, using "nerve regeneration," treats shell-shocked English soldiers in order to return them to the trenches, now reactivated for further destruction. When the powers that be send poet Siegfried Sassoon to Rivers, the moral ambiguities deepen. Sassoon, who is not shell-shocked despite his battle experience, has become a conscientious objector to the war. He may even be the sanest individual in England. Will the doctor "cure" him and send him back to the front lines?



***Gravity's Rainbow*, by Thomas Pynchon**

This difficult and rewarding novel, spanning dozens of themes beyond the mere question of the human as a mechanism, is laden with characters seeking to understand what forces are manipulating them. As more and more characters seek to decrypt the physics and metaphysics of human control, however, they paradoxically outsource the question of how they may salvage their own individual souls and their interpersonal relations.

***A Foray into the Worlds of Animals and Humans*, by Jakob von Uexküll**



"Whoever wants to hold on to the conviction that all living things are only machines should abandon all hope of glimpsing their environments," Uexküll writes on page 1 of this fascinating book, claiming that biology and ecology depend on studying every species as inherently subjective and world-building. In this manner, he likens the organism to a combination of "machine" and "machine operator" and thus distinguishes himself from behaviorists. In clear prose, and with wonderful facts and observations, he describes the *Umwelten* — subjective environments — of ticks, worms, snails, moles, and humans.

THE COLOPHON: UPDATES FROM THE SFI PRESS

Q&A: *Scaling in Biology* 2.0

Later this year, the SFI Press will publish an update to the canonical *Scaling in Biology*, a field-defining text originally published by Oxford University Press in 2000. The forthcoming volume will be edited by SFI Resident Professor Christopher Kempes and External Professors Brian Enquist (University of Arizona) and Mary O'Connor (University of British Columbia). We recently sat down with Kempes to discuss the book's roots and focus.

SFI PRESS: Why is scaling important?

CHRIS KEMPES: Scaling represents one of the most comprehensive theories in biology, touching on everything from the physiology of single cells to the structure of entire forests. In most cases, the key results are derived from fundamental principles, represent compact theories, and explain a wide variety of results. For example, we understand why bacteria dilute in cellular chemical concentrations as they get bigger, why forests have a certain distribution of tree sizes, and what sets the limits to the tallest trees and biggest mammals.

***Scaling in Biology* is a foundational volume on the topic. How has that early work on scaling influenced your own?**

I encountered the book as an undergraduate a few years after it had been published. It provided me with a window into both the overarching concepts, arguments, and philosophy of scaling as well as fascinating detailed case studies. My work in scaling has always been at these two levels: working on the synthetic level of crosscutting theories and the philosophical implications of such theories, and solving detailed problems for specific biological contexts.

How have your collaborations at SFI shaped your interest in scaling?

My scaling collaborations at SFI are actually basal, as I spent an independent study and then a summer as an undergrad at SFI collaborating with Geoffrey West and Michelle Girvan. Since then, my range of SFI topics and activities has greatly expanded into areas that are unrelated to scaling.

What prompted you and your coeditors to create a kind of sequel to the 2000 volume?

A huge amount of progress has been made over the last 30 years in scaling theory, yet it is often underappreciated and underused within the biosciences. Old controversies have also persisted, even though many have been dealt with in an evolving and expanding theory. We wanted to have a workshop centered on synthesizing this progress, and it was natural to connect a collected volume to this workshop.

What aspects of the editorial process do you find most challenging? Rewarding?

People have a lot of fascinating things to say, and there is only so much space; the proverbial writing advice of "kill your darlings" is ever-present, perhaps more so, as an editor of others' contributions. I have always found that the service of a good editor is pointing out what doesn't work in a piece, what is tangential, and what can be eliminated as unnecessary. As an editor, I am finding that this can be a source of friction when dealing with the "darling" sentences and sections of others.

BEYOND BORDERS *(cont. from page 2)*

near arbitrary complication could be solved through scale.

Computer scientists build architectures that seek to be spirit-proof. When physicists criticize biology for having too many parameters, they are applying parametric parsimony where processual parsimony is the goal. And when biologists accuse neuroscience of ignoring evolutionary constraint, they are importing processual parsimony into a domain governed by architectural parsimony. Each field is haunted by a different ghost, exists in a different intellectual bardo, each governed by its own rituals.

The old disciplinary ghosts aspired to be ontological, frightening entities posited to occupy ordered states of reality, from which ensuing and more skeptical generations banished them. We now have epistemic ghosts, patterns in large datasets, manifesting as regularities, correlations, and structures, that no human theorist seems to have previously named or noticed. LLMs suggest that we have been haunted by vast domains of regularity, in language, protein folding, weather, and genomics, that are simply too high-dimensional for human intuition to observe but not too complex for a sufficiently scaled statistical model to discern.

The ghosts are multiplying, many of them hallucinations, and scientific exorcists must learn new rites.

— David Krakauer
President, Santa Fe Institute

ACHIEVEMENTS


Kaleda Denton


Marina Dubova

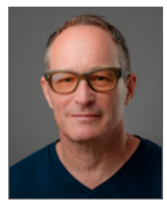

Brian Enquist

SFI Complexity Postdoctoral Fellow **Kaleda Denton** was selected to participate in the Rising Stars in Computational and Data Sciences annual workshop, which was hosted at SFI in April.

The Cognitive Science Society and the Glushko-Samuelson Foundation have awarded SFI Complexity Postdoctoral Fellow **Marina Dubova** one of five 2026 Glushko Dissertation Prize for groundbreaking work in cognitive science.

SFI External Professor **Brian Enquist** was awarded the Ecological Society of America's Robert H. MacArthur Award, celebrating "meritorious contributions to ecology, in expectation of continued outstanding research."


Simon Levin


John Krakauer

Last fall, SFI Professor **John Krakauer** was named director of Champalimaud's Centre for Restorative Neurotechnology.

In May, SFI Science Board Fellow **Simon Levin** was named a Fellow of the Royal Society.


Han van der Maas


Nicholas de Monchaux

SFI External Professor **Han van der Maas** was named the next director of the University of Amsterdam's Institute for Advanced Study, with a five-year term beginning in September.

SFI External Professor **Nicholas de Monchaux** was named the new dean of UC Berkeley's College of Environmental Design (CED), with a term commencing July 1, 2027.


Allison Stanger


Andreas Wagner

SFI External Professor **Allison Stanger** has been named a Berlin Prize Fellow by the American Academy in Berlin for the 2026–27 academic year.

SFI External Professor **Andreas Wagner** received a EUR 2.5 million Advanced Grant from the European Research Council to support his work on fitness landscapes over the next five years.

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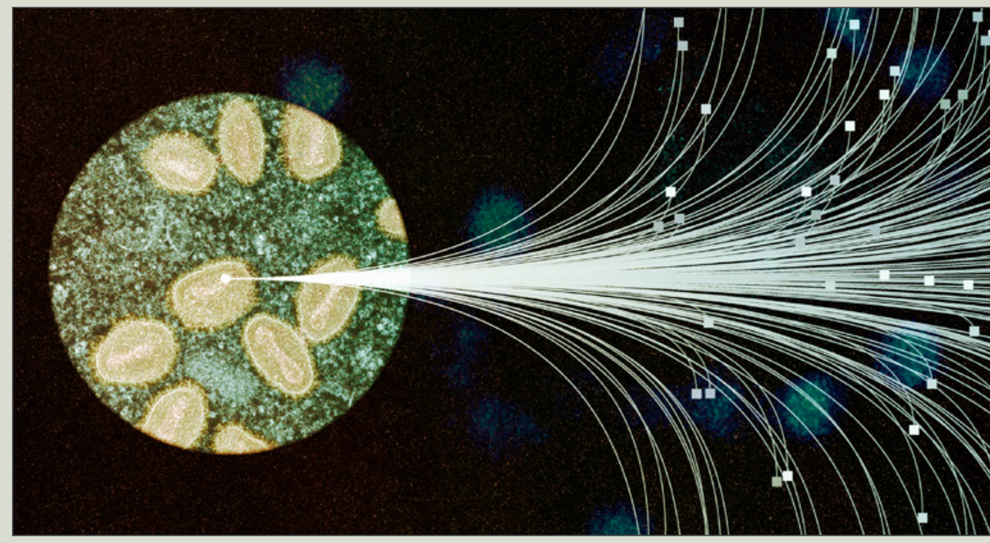
RESEARCH NEWS BRIEFS


Multiroute pathogens don't behave like single-route ones. The models are only just catching up. (image: Edson De la O/SFI)

MULTIROUTE PATHOGEN TRANSMISSION IS DIFFERENT

From HIV and hepatitis C to Zika, Ebola, and mpox viruses, the list of pathogens that can be transmitted in more than one way is growing rapidly. In a Focus article recently published in *Science Advances*, SFI External Professor Samuel Scarpino (Northeastern University) explains why new modeling techniques are needed to capture the dynamics of multiroute pathogens, since they behave far differently than single-route pathogens.

In the overview, Scarpino highlights another paper in the same issue that develops a multiroute transmission model to study the spread of mpox in the Democratic Republic of the Congo. When mpox started to affect children more often than adults in the DRC, some researchers thought the virus had changed evolutionarily. But more recently, others proposed a different possibility: that mpox's multiple simultaneous transmission routes could alone account for these shifting patterns.

In the near future, Scarpino argues, infectious-disease epidemiologists will need to consider multiple transmission routes when studying pathogens. Current mathematical and computational tools have begun to more fully embrace epidemics as complex systems, but to truly advance epidemiology, scientists must continue to challenge current models with real-world data and cooperate both internationally and across disciplines.

Read the Focus article "Multiroute pathogen transmission is different" in* Science Advances. *DOI: 10.1126/sciadv.aeg9143

COORDINATING INTERNATIONAL OPERATIONS WITH "SPACE DIPLOMACY"

In aviation, countries control their airspace and direct air traffic, but they also adhere to shared protocols that allow thousands of planes to traverse international airways without colliding. Something analogous is needed in space.

In a comment article, "Space diplomacy: bridging the operating gaps between myriad missions," which was recently published in *Nature*, SFI External Professor France Córdova, lead author Gioia Rau, and other co-authors propose that governments, scientific institutions, and commercial enterprises are in urgent need of a shared framework to coordinate operations in space. Satellites and space debris are cluttering up low Earth orbit, and the lack of communication among actors with conflicting interests has resulted in confusion and a heightened risk of collisions.

Because spacecraft can't be modified once launched, the authors argue that coordination requirements must be embedded into licensing and system design from the outset. To enforce this standard and others, the researchers lay out five areas of focus: the need for a neutral group to measure progress and keep track of the adoption of standards, the protection of dark and quiet skies, the necessity of collaboration between research organizations and policymakers, the key role of philanthropy as a catalyst for pre-competitive coordination infrastructure, and the importance of effective communication about the cost, risk, and public value of missions to space. As more actors enter orbit, the authors argue, space diplomacy will be essential not only for avoiding collisions, but for preserving dark skies and curating space as a shared scientific, commercial, and public resource.

Read the paper "Space diplomacy: bridging the operating gaps between myriad missions" in* Nature. *DOI: 10.1038/d41586-026-01298-x

A SIMPLE BASELINE FOR AI FORECASTING IN MACHINE LEARNING

In a recent paper, SFI Complexity Postdoctoral Fellow Yuanzhao Zhang and co-author William Gilpin show that a deceptively simple forecasting strategy can outperform several leading machine-learning forecasting models.

Their method, called context parroting, relies on small portions of time-series data. It works by comparing a short stretch of the time series with earlier parts of the same sequence, identifying similar patterns or motifs, and using what follows those earlier patterns to predict what might come next.

Researchers need to be careful when judging the performance and intelligence of AI systems and must keep working to open up the black box of how they make predictions, says Zhang, and this paper is a reminder about why.

The paper's three main contributions reinforce that message. First, it introduces context parroting as a strong and surprisingly effective baseline for zero-shot forecasting, which means predicting a new system from only a short stretch of data and no prior training on that specific system. Second, it shows that this simple approach can outperform current leading models on difficult prediction tasks such as chaotic systems dynamics. Finally, it explains why forecast accuracy improves as more context is provided, with the rate of improvement linked to the complexity of the system being predicted.

The paper was presented at the International Conference on Learning Representations in Rio de Janeiro, Brazil, April 23–27.

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E-PARALLAX

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