SUMMER 2023

Parallax

THE NEWSLETTER OF THE SANTA FE INSTITUTE

AI-generated art using Diffusion Bee. (image: Laura Egley Taylor)

SFI hosts first conference-style event

SFI hosted its first conference-style event June 20–22 at the La Fonda Hotel in Santa Fe, New Mexico. The event — a combined symposium and short course — focused on the foundations of collective intelligence, drawing over 200 in-person and 150 virtual attendees.

"From a conceptual standpoint, collective intelligence is a sub-discipline of the study of collective phenomena and pattern formation but where the emphasis has been more on the function of collective pattern formation than on how those patterns form," says co-organizer and SFI Professor Jessica Flack. "The latter question — how patterns form in space and time — is a familiar one within complexity science, with the study of spatial pattern formation largely drawing on tools and concepts from statistical mechanics, and the study of patterns in time, largely drawing on tools and concepts of dynamical systems. An objective of this meeting was to begin more effectively bridging collective pattern formation with the study of when those patterns have value."

The first day of the meeting focused on first-principles approaches from the physical and natural sciences for deriving group performance from microscopic, individual-level behavior and interactions. On day two, presentations addressed the nature of intelligence in collectives, including large language models like GPT-4, AI, and economic systems. Speakers and meeting participants on the third day discussed the dynamics of collective intelligence, the nature of intelligent solutions under uncertainty, and collective epistemologies. In the final discussion, Flack addressed with artist, social activist, and filmmaker Godfrey Reggio the role of collectives in harnessing radical ideas and innovation, using his groundbreaking film *Koyaanisqatsi* as a lens and example.

"The structure of this event really lent itself to a comprehensive consideration of collectives across scale. The cognitive diversity represented by our slate of speakers contributed to a truly interdisciplinary exploration that, while par for the course for any private SFI event, made for a unique and refreshing 'conference' experience for our attendees," says co-organizer Caitlin McShea, SFI's Director of Experimental Projects.

A highlight of the symposium was the rooftop poster party where poster presenters discussed their work with meeting participants. The poster prizes were announced at Meow Wolf's "House of Eternal Return," an immersive art installation conceived and executed by a

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Dan Tierney elected to Board

The Santa Fe Institute's Board of Trustees welcomed Dan Tierney as a new member during the May 2023 Science Board & Board of Trustees Symposium. Tierney, an investor and the founder of Wicklow Capital, describes himself as a systems thinker, innately drawn to interdisciplinary approaches and innovation.

"I love the chance to be part of bringing new ideas into the world," he says. At the recommendation of three different friends who thought he would resonate with SFI's philosophy of convening people of varied perspectives, he began attending ACtioN events. "They were right," he says. "This is a place I want to be part of."

Tierney launched his career in financial markets on the trading floor in Chicago. It was a natural step — he'd started brokering a toy trade among his friends at the age of nine — but the trading floor ultimately proved to be not quite the right fit. After he left, he launched one of the world's first automated trading companies, Global Electric Trading Company (GETCO), in 1999 with a colleague from another exchange.

"It was an amazing 12-year journey," he says, "but I ultimately realized that I loved innovation even more than financial markets."

So, in 2012, he turned the reins of GETCO over to new leadership and founded Wicklow Capital. Through this family office, he pursues venture investing and venture philanthropy in what he calls the A-B-C-Ds of the world's emerging and most important paradigms — AI, Blockchain, Climate, and Democracy.

Serving on an institute's board offers opportunities both to help and to learn, says Tierney, who is also a member of the Board for the Salk Institute. "I'm still no expert in biomedical research, but I know infinitely more than I did before," he says. At SFI, he is looking forward to participating in conversations about the potential benefits and risks of artificial general intelligence, how AI and blockchain may be synergistic, and what the next version of democracy needs to look like to thrive in a post-industrial, information-age world.

"If anyone can figure that out, SFI is the kind of place that can do it," he says.

Complexity solutions for 21st-century challenges

When COVID-19 hit, SFI External Professor J. Doyne Farmer (University of Oxford) wanted to use his expertise to help predict how the economy would respond to the emerging pandemic. But the realities of COVID-19 — like so many of the concerns humanity currently faces — didn't fit neatly into standard economic theory. It meant that he and his colleagues had to build new models based on "complexity economics" to make those predictions.

Traditional economic models assume supply and demand are in equilibrium and that "rational" decision-makers "use all available information to make the best possible decision — the one that yields highest utility," Farmer writes in his book, *Making Sense of Chaos*. Complexity economics, on the other hand, "assumes from the outset that agents are 'boundedly rational,' with limited ability to reason, who make imperfect decisions."

In an recent SFI workshop, Farmer and others applied approaches from complexity economics to make sense of some of society's trickiest issues. The workshop, "Complex System Approaches to 21st-Century Challenges: Inequality, Climate Change, and New Technologies," ran July 31–Aug. 2 and was part of SFI's new Emergent Political Economies program.

The workshop included some 60 representatives of multiple disciplines, countries, and organizations, as well as practitioners and funders "to make sure that the research that's coming out of this project is getting into the hands of people who can actually use it," says Travis Holmes, SFI's EPE Program Manager.

That's what SFI External Professor Jenna Bednar (University of Michigan), a workshop co-organizer, says gets her excited. "It's very intentionally focused on concrete problems in the world." Participants included academics who brough "a lot of really good data for us. And they just don't know how to make sense of those data," she says. The hope is that complexity science can "start to give them some tools for analysis."

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Smoke from Canadian wildfires engulfs New York City in the summer of 2023. (image: Ahmer Kalam/ Unsplash)

INSIDE: In memoriam — Cormac McCarthy, James Hartle & James Pelkey . . . Sensory prediction . . . MORE

BEYOND BORDERS

"Between The Bauhaus and Bell Labs"

The employees of Bell Telephone Laboratories described the company as an "institute for creative technology." According to Jon Gertner, the historian of Bell Labs, "This description aimed to inform the world that the line between the art and science of what Bell scientists did wasn't always distinct."

In one of several Bauhaus manifestos written by Walter Gropius in the nineteen-teens, Gropius described the aim of the new school as bringing craftsmen and artists together to create "the building of the future."

There is a charming correspondence between the idea of a Bauhaus "building" and a Bell Labs "technology": they both encompass more or less everything. For Bell Labs, communication and the transistor provided unifying technologies around which to build new systems of telephony, computers, psychology departments, language processors, and music and art software. At the Bauhaus, architecture provided a focus for the creation of typography, sculpture, furniture, art, cutlery, and books.

A slightly closer analysis of the history of these two institutions reveals a few basic ingredients of culture that provide clues to the scope of their influence. First and foremost, a focus on rigorous capability and creative freedom in community, and secondly, a healthy disregard for boundaries and benchmarks of disciplinary performance. Speaking about Claude Shannon, Gertner writes, "When confronted with ordinary number problems — 18 × 27, for instance — Shannon would work them out not in his head but on a blackboard. He wasn't much for details; sometimes he would solve problems in a way that showed surprising intuition but a mathematical approach that some colleagues found unsatisfactory or lacking in rigor. Above all, he almost seemed more interested in doing work with his hands than with his mind."

The focus on thinking with all of one's sense and sensibility was a dominant feature of the Bauhaus, where according to the art historian Magdalena Droste, "[t]hanks to their basic training on the hand loom, however, students were equally capable of running small, artistic crafts workshops" and "A profession was thus created within the textile industry which had rarely been found before — designer."

Between the engineering design of Bell Labs and the artistic design community of the Bauhaus, I like to position the Santa Fe Institute. Complex systems are that special part of the universe "designed" by natural selection and self-organizing dynamics or by human collectives: organisms, ecosystems, markets, computers, and

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www.santafe.edu

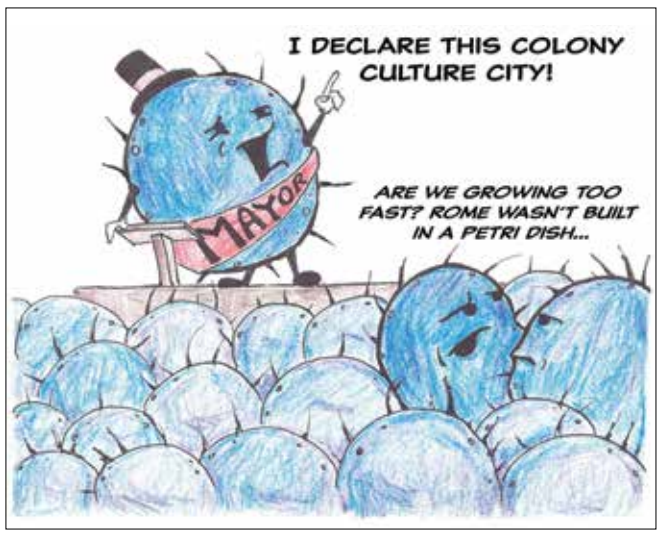
Regulatory mechanisms from cells to societies

In Leonard Read's 1958 essay, "I, Pencil," the renowned economist explains how making even the simplest of writing utensils requires millions of people working together in a complex division of labor.

Fast forward to today's modern world, and that division of labor in everything from global production lines to university bureaucracies has grown both in scale and complexity. The trend has led to what many view as an alarming increase in the use of regulatory mechanisms — such as companies hiring additional managers or government agencies performing more audits — to ensure many complex social systems run smoothly.

"It ultimately begs the question: how much regulation is too much regulation, and what does optimal even look like?" says SFI Professor Chris Kempes. "I would say we don't know what optimal regulation looks like nor how to evaluate it, which is surprising because pretty much all complex systems from individual cells and bacteria to large corporations and economies require some form of regulation to work coherently."

Kempes and SFI External Professor Hyejin Youn (Northwestern University) organized an SFI workshop that ran June 13–15 to better understand these optimal regulations in diverse fields, ranging from biology and physics to corporate management. The participants' overarching goal was to identify commonalities among the regulatory mechanisms identified in different systems. This could ultimately enable researchers to apply optimal regulations from one field of study to another.



(illustration: Adam Copeland/SFI)

"I think what is new here is that we are trying to build an overarching framework of regulatory mechanisms that can go from one disparate system such as a cell all the way to a human society," Youn says. "The goal is really to be able to determine whether the regulatory mechanisms in something like a cell or human organ can be applied to a social system or not. Maybe yes, maybe no. We are working on developing a common typology to better answer these types of questions."

Former SFI Postdoctoral Fellow Vicky Yang (MIT) and SFI Professors Sidney Redner and Geoffrey West also helped organize the workshop, which was funded in part by the National Science Foundation.

Harnessing sensory prediction for nonliving systems

Prediction is a key part of complex systems, in a wide variety of fields. Physicists and mathematicians use prediction performance to evaluate their models of mechanical systems; engineering prediction algorithms can inform the design of complicated devices. Prediction is also integral in artificial intelligence, in large language models like ChatGPT, which are designed to predict a word or words that follow from a prompt.

But living organisms use prediction, too, and it's critical to life itself. They must predict what actions will lead to food, or how changes in the environment will affect their well-being.

"Prediction is really important for everything organisms do," says Claremont McKenna College physicist Sarah Marzen, a co-organizer of a July 10–14 workshop at SFI called "Sensory Prediction: Engineered and Evolved."

"A lot of what biological systems have to do to survive is to predict," says co-organizer James Crutchfield, an External Professor at SFI (University of California, Davis).

Crutchfield and Marzen both focus on ways to use ideas from physics to predict how organisms make predictions — which is often more complicated than mechanical systems. They note that if researchers can better understand prediction in living systems, they could build models of those decisions and use that knowledge to inform prediction algorithms in other areas.

Their workshop explored this crossroads. The meeting brought together neuroscientists, physicists, computer scientists, mathematicians, biologists, and others to explore how a better understanding of predictions from biological sensory systems might influence prediction in application to other scientific domains.

Marzen says the workshop's goal was to develop a unifying framework for sensory prediction, including both a way to measure efficient prediction and some theoretical understanding for how it made predictions. The way the researchers framed the questions that motivated the workshop, says Crutchfield, largely emerged from the physical sciences, but the work could provide new insights in theoretical biology, neuroscience, and other disciplines.

Organisms use a variety of senses to glean information and make predictions that are critical to their survival. A better understanding of sensory prediction in living systems could help improve prediction in other realms. (image: Christian Lue/Unslpash)

Postdocs gather for 72 Hours of Science

In the high-desert landscape between Santa Fe and Eldorado, nine of SFI's postdocs gathered in late May at a quiet rental for 72 Hours of Science — an intense annual three-day retreat of community-building, creativity, and mad-dash research.

"I'd heard good things about previous years' 72 Hours of Science," says James Holehouse, who began his postdoctoral fellowship at SFI last fall. He wanted to experience it, so he volunteered to co-organize the event. "At SFI, you are already relatively free to explore unconventional ideas. In 72 Hours, you are even freer to throw ideas around. When you have a lot of ideas, some of them will be good."

Inspired by the format of 24-hour film festivals, 72 Hours of Science offers a space for blue-sky thinking under tight time constraints with the goal of putting each postdoc's talents to use. Participants arrive with a bevy of ideas, which they pitch, workshop, and whittle to a small set of contenders before voting on a final topic.

The group quickly eliminated questions where data would be too difficult to obtain — the main sticking point for many of the ideas — or topics that were too narrow to include everyone's skill sets. Riffing on an idea popular at SFI and in the broader science community, they eventually chose the theme "The Science of the Science of Science."

In a paper published in *Science* in 2018, Santo Fortunato and co-authors wrote, "The science of science (SciSci) places the practice of science itself under the microscope." It uses large datasets to analyze how science is done, considering everything from how scientists choose research questions to the paths their careers follow. In a meta approach, the Science of SciSci would turn the microscope back on SciSci itself.

"It's a new spin on an old field," says Postdoctoral Fellow George Cantwell. "Some of the science of science analyses make prescriptive claims about how one should do science in order to have a good career. We wanted to ask: are those researchers following their own advice?"

SFI Postdocs gathered for the 2023 72 Hours of Science. [L–R] Mingzhen Lu, George Cantwell, Veronica Roberta Cappelli, Daniel Muratore, James Holehouse, Maell Cullen, Ignacio Arroyo, Andrés Ortiz-Muñoz. (image: Katherine Mast/SFI)

Cantwell says he's not sure what "success" would mean for 72 Hours of Science. "There is a conservative mentality among scientists, and for good reason," he says. Hasty data collection and analysis lead to untrustworthy results. "But it's also a barrier." While the compressed nature of 72 Hours of Science likely won't result in solid research, three days is enough time to land on an ambitious

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Insights about phase transitions in matter — like when ice melts to become liquid water — may apply to sprawling datasets, too. (image: Taylor Cole/ Unsplash)

Phase transitions in big data

In the field of computational complexity, a problem is deemed "easy" if it can be solved by an algorithm in a reasonable number of steps. A problem is "hard" if its solution requires an astronomical number of steps that grow exponentially with its size — often because it requires a brute-force search. These definitions are particularly apt in the era of big data, where problems related to finding patterns in huge amounts of noisy data may be easy, hard, or impossible.

> What an algorithm is trying to do, when it's looking for a signal, is a lot like crystallization.

Many of these problems are believed to undergo a kind of transition, from easy to hard, analogous to phase transitions in matter, like when a solid — an orderly arrangement of particles — melts to become liquid — which is more disorganized. It's a powerful comparison, says SFI Professor Cris Moore, who works at the crossroads of physics, math, and computer science.

"The noise in a dataset is heat, in this analogy," he says. "In some sense, what an algorithm is trying to do, when it's looking for a signal, is a lot like crystallization." It's looking for clear patterns against a messy backdrop. "When the data are too hot and noisy, the algorithm can't settle down or find the true pattern."

By using knowledge of phase transitions in physical systems, researchers can gain new insights into more efficient ways to answer questions about patterns and structures in sprawling datasets. Moore recently organized a working group, held July 17–21 at SFI, that brought together experts from computer science, physics, and mathematics to explore connections between theoretical computer science and spin-glass theory, which is a framework for understanding phase transitions in complex materials.

Interest in the overlap between the two areas has grown in the last two decades, says Moore, as researchers have identified two kinds of phase transition in data. "If there's only a small amount of noise, the signal comes through easily, and fast algorithms can find it," he says. "But as the noise increases, the problem jumps from easy to hard, like window glass never finding its crystalline state. And at an even higher level of noise, the problem becomes impossible — the signal gets lost in the noise."

Making those connections, says Moore, is at the heart of the working group. "This meeting is about an ongoing effort to build the bridge between the physics — which is very convincing, but not mathematically rigorous — and rigorous techniques in mathematics and statistics," he says.

COLLECTIVE INTELLIGENCE *(cont. from page 1)*

collective of 108 local artists. Steven Ceron won first prize for "Emergent Behaviors of Janus Swarming Oscillators." Guillaume Falmagne, Anna B. Stephenson, and Simon Levin received second place for "Surveying Early Warning Signals of Transitions Using a Large-scale Collaborative Experiment." There was a three-way tie for third place: Robert Passas, Brennan Klein, Eli Sennesh, and Jordan Theriault for "Agent Based Feedback Models of a 'Sense of Should'"; Eddie Lee for "Following the Information Footprint of Firms;" and Golnar Gharooni Fard, Morgan Byers, Varad Deshmukh, Chad Topaz, Elizabeth Bradley, and Orit Peleg for "Spatiotemporal Dynamics of Food Exchange Networks in Honeybees."

Madalina Sas at the rooftop whiteboard session during the Collective Intelligence Symposium and Short Course. (image: Genevieve Russell)

21ST-CENTURY CHALLENGES *(cont. from page 1)*

On a local scale, Bednar offers the example of affordable housing as a "thorny, thorny problem that leads to so many other problems," potentially affecting everything from mental health to employment, family relations, and the likelihood of experiencing violence or abuse. "Housing is not some sort of issue that you can isolate," she says, yet the social sciences don't often have the tools to develop models that take that sort of complexity into account.

Climate change is another key example. "Traditional economics models have so far made terrible predictions about the climate transition," Farmer says. Those models have overestimated the price and implementation times of new renewable technologies like solar, wind, and batteries. "This has led to overestimates of the cost of the transition, which has slowed the transition down," he says.

In the long term, Farmer says, he hopes for another type of transition in which complexity economics "will surpass and largely take over traditional economics. My hope for the workshop is that it will help create a strong community of complexity economics modelers."

Feasible metabolisms

From the perch of modernity, it is tempting to envision the limbs of the tree of life as inevitable, a steady march toward existence from one generation to the next. Some branches in the tree are shorter than others, of course — tales of extinction, from the asteroid-blasted dinosaurs to the human-blasted passenger pigeon, offer a tragic alternative vision of what life on Earth could look like today.

Perhaps even more tantalizing, however, are life's near misses — the unformed pathways lurking in the shadows of evolution.

"Evolution is contingent," says SFI Professor Chris Kempes. "Sometimes it can ignore whole spaces of potential discovery."

> Known energetic pathways only represent a fraction of the metabolic pathways do — or could — exist.

Kempes is co-organizing an August working group — the second in a series — focused on these spaces of undiscovered life. The meeting, "Feasible but Undiscovered Metabolisms II: Thermodynamics, Evolution, and the Origin of Life," comprises a diverse group of origin-of-life researchers including theorists and experimentalists who study Earth history, fundamental thermodynamics, cell physiology, and genome evolution.

"Part of what we're doing in this workshop is to expand our knowledge of what is going on in our contemporary biosphere, but to also think outside it," says co-organizer Shawn McGlynn, an Associate Professor at Tokyo Institute of Technology, Earth Life Science Institute.

Specifically, the researchers are focused on metabolisms, or how organisms harvest energy from the surrounding environment. Metabolisms on Earth are diverse: plants photosynthesize, chemoautotrophs harvest energy from the Earth's crust, and humans, like other heterotrophs, are powered by consuming other organisms. But known energetic pathways only represent a fraction of the metabolic pathways that do — or could — exist.

One goal of the working group is to define, based on universal laws of physics and chemistry, the physical boundaries of life, on Earth and beyond.

"If we can understand the diversity of how life works, we'll be in a better position to hypothesize about what life may have been like in deep time and to imagine possibilities for the future of life on Earth, or even life on other planets," says McGlynn.

The meeting is the final event covered by the National Science Foundation Origins of Life Research Coordination Network grant based at SFI. While the next steps for this work are undetermined, the group is discussing how to move forward and further the ideas that have come out of the five-year project.

What we're reading

Books chosen by the SFI community on Catastrophe

Throughout our cultural history, from the Chauvet Cave paintings and the *Epic of Gilgamesh* to Virgil's *Aeneid*, Turner's "The Burning of the Houses of Lords and Commons," Picasso's "Guernica," and Alexeivich's *Voices from Chernobyl*, poets and painters have achieved great success in depicting catastrophic events — whether natural disasters or those instigated by human folly. All-encompassing wars, hurricanes and tempests, famines, earthquakes, genocides, plagues, floods, fires, and full-blown apocalypses: such subject matter engages the epic tendency in our most talented artists, and, as spectators, we gravitate towards these representations of otherwise unimaginable calamity.

In *White Noise* — a novel with its own catastrophe in the form of an "airborne toxic event" — Don Delillo suggests that "Only a catastrophe gets our attention. We want them, we depend on them. As long as they happen somewhere else." Artwork has the magic ability to fulfill this dependency, providing proximity to calamities that happen elsewhere while paradoxically allowing us to remain safely remote, in what critic Edward Bullough has called "the antimony of distance."

Even so, Delillo's cynical take may be overshadowed by the three books featured in this installment of What We're Reading. In each, it is not the catastrophe itself that generates interest, but the sublime and varied human responses to it. Whether through moral resilience, storytelling, scientific innovation, artistic and intellectual mastery, or love and community, the human spirit remains unconquered despite its dire circumstances. While capitalizing on the antinomy of distance, each of these books somehow brings us closer to the human beings tasked with both overcoming and learning from catastrophe.

ANTHONY EAGAN
SFI Research Fellow

The Road by **Vasily Grossman**

Grossman was one of the great chroniclers of the 20th century's human-made catastrophes. Though the eclectic short pieces comprising The Road are sometimes bleak, their beauty and humanity tend to balance out the painful subject matter. Featured in this collection are "The Hell of Treblinka," which should be universally required reading, and "The Sistine Madonna," a reflection on the "immortal" power of art in a time of outrage.

KATHERINE MAST
Manager of Publications

Island on Fire by **Alexandra Witze** and **Jeff Kanipe**

When Iceland's Lakagígar fissure erupted in 1783, its eight-month stream of molten rock and toxic gases killed at least half of Iceland's livestock, caused widespread famine, and had global climatic consequences. Island on Fire offers a conversational and well-researched look at volcanoes throughout Earth's history, stories of the people who experienced the Laki eruption, and what it might mean if a Laki-scale event were to happen in our lifetimes.

ELLIS WYLIE
SFI Archivist/Editor

A Children's Bible by **Lydia Millet**

Millet's cli-fi allegory for a future "now" is not so much dystopian as it is dire. It's like *Lord of the Flies* meets *The Goonies* meets *Deliverance*, with modern-day tech and a dearth of banjos. The humor and wit of a group of wayward children, juxtaposed with the hedonism and helplessness of their parents, sets the tone of this novel. Not your average summertime beach book, *A Children's Bible* is a quick, ever-changing read that examines the infinite human capacity for resilience.

Reimagining the future of publishing — and science

In a new series for Parallax, the SFI Press team offers an insider's peek at the works featured in their growing list of volumes.

In 2017, the Santa Fe Institute Press launched on the principle that excellent scholarship should be accessible and affordable. Like its namesake institute, the SFI Press is interested in giving voice to big, novel ideas — from understanding how computational tools are transforming the study and practice of law to visualizing the emergence of social behavior in a system — that ultimately have a deep impact on how we make sense of the world.

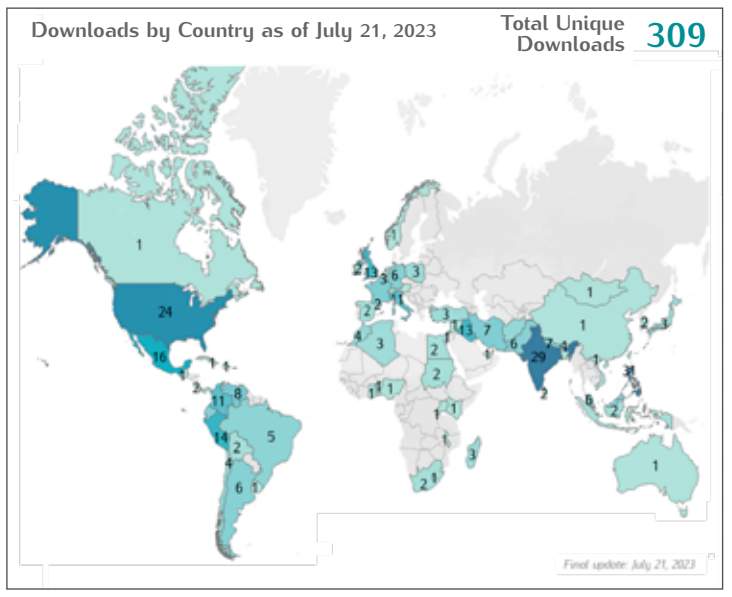
In an age when academic texts can cost hundreds of dollars and take years to see publication, the SFI Press ensures that the research of complexity scientists reaches audiences around the world quickly. Its books are priced near cost, contain thoughtful, deliberate design, and include technical monographs, interdisciplinary textbooks, symposium transcripts, and reprints of still-relevant works from past decades. Its 13 titles published so far have seen more than 35,000 copies sold and distributed worldwide, and are meant to spark new ways of thinking across both geographical and disciplinary boundaries.

"The notoriously high price of scholarly books belies their primary purpose — to disseminate knowledge," says SFI President David Krakauer, Editor-in-Chief of the SFI Press. "It's driven academics to read only the volumes they can borrow through their institutional libraries and the wider readership to ignore these writings altogether."

With this goal of true accessibility in mind, the SFI Press is working with institutions around the world to disseminate complexity science. They recently partnered with Physics Without Frontiers at the International Centre for Theoretical Physics to provide a free digital copy of *Complexity, Entropy & the Physics of Information* — a reprint of the 1990 seminal volume edited by physicist Wojciech H. Zurek — to an international network of students and experts. With more than 300 unique downloads to date, this initiative has reached communities across South America, South and East Asia, and the Middle East, where access to scientific research has historically been limited.

The number of books in its queue continues to grow, and the SFI Press is preparing two multi-volume projects for publication in the coming months. In late 2023, the SFI Press will publish a trio of books honoring the memory of Nobel Prize-winner and SFI Co-Founder Murray Gell-Mann. Next year, they will release *Foundational Papers in Complexity Science*, a multi-volume collection of 20th-century papers influential to the emergence of complex-systems science, edited by Krakauer and introduced and contextualized by members of the wider SFI community. With each new publication, the SFI Press remains committed to drawing wide audiences to ideas at the frontiers of complexity science and reimagining the future of academic publishing to serve the scientific community.

COMPLEXITY, ENTROPY & THE PHYSICS OF INFORMATION
July 2023 ICTP Physics Without Frontiers Partnership



Through a month-long partnership with Physics without Frontiers at the International Centre for Theoretical Physics, the SFI Press offered its most recent book, Complexity, Entropy & the Physics of Information, as a free download. The initiative resulted in more than 300 copies reaching people in 71 countries. (image: SFI Press)

SFI PRESS 2023–2024
CATALOG OF TITLES

Complexity, Entropy & the Physics of Information Vol. 1 (2023)
Wojciech Zurek, ed.

Agent-Based Modeling for Archaeology (2021)
Iza Romanowska, Colin D. Wren & Stefani A. Crabtree

InterPlanetary Transmissions: Genesis (2019)
David C. Krakauer & Caitlin L. McShea, eds.

Complexity, Entropy & the Physics of Information Vol. 2 (2023)
Wojciech Zurek, ed.

Complexity Economics (2020)
W. Brian Arthur, Eric D. Beinhocker & Allison Stanger, eds.

The Energetics of Computing in Life & Machines (2019)
David H. Wolpert, Chris Kempes, Peter Stadler & Joshua A. Grochow, eds.

Ex Machina: Coevolving Machines & the Origins of the Social Universe (2022)
John H. Miller

InterPlanetary Transmissions: Stardust (2020)
David C. Krakauer & Caitlin L. McShea, eds.

Worlds Hidden in Plain Sight: The Evolving Idea of Complexity at the Santa Fe Institute, 1984-2019 (2019)
David C. Krakauer, ed.

The Complex Alternative: Complexity Scientists on the COVID-19 Pandemic (2021)
David C. Krakauer & Geoffrey West, eds.

Law as Data: Computation, Text & the Future of Legal Analysis (2019)
Michael Livermore & Daniel Rockmore, eds.

Emerging Syntheses in Science (2019)
David Pines, ed.

The Emergence of Premodern States (2018)
Jeremy A. Sabloff & Paula L. W. Sabloff, eds.

History, Big History & Metahistory (2017)
David C. Krakauer, John Lewis Gaddis & Kenneth Pomeranz, eds.

NEXT UP

The Quark & the Jaguar: Adventures in the Simple & the Complex (MURRAY GELL-MANN)
Strange Beauty (A BIOGRAPHY OF MURRAY GELL-MANN BY GEORGE JOHNSON)
Strangeness: A Celebration of Murray Gell-Mann (EDITED BY DAVID C. KRAKAUER)

Foundational Papers in Complexity Science
(A FOUR-VOLUME SET CURATED BY DAVID C. KRAKAUER)

SCAN TO VIEW
SFI PRESS BOOKS

IN MEMORIAM

SFI remembers three important members of our community who passed away this year. For longer versions of these stories, including reflections by SFI friends and colleagues, please visit www.santafe.edu/news.

Cormac McCarthy

[Clockwise from top left] Cormac at La Fonda Hotel in 2023. (image: Kate Joyce); James Drake, Cormac, David Krakauer, Walter Fontana, and Sam Shepherd in 2011. (image: courtesy of James Drake); David Krakauer presents a cake for Cormac's 89th birthday. (image: Kate Joyce); Murray Gell-Mann, Cormac, and Geoffrey West in 2009 (image: Laura Ware); Andrea Wulf and Cormac in 2023. (image: Kate Joyce); Geoffrey West, Fred Cooper, Patrisia Brunella, and Cormac at the Cowan Campus in 2013. (image: Scott Wagner); Della Vigil shares memories at a special tea remembering Cormac in 2023. (image: Katherine Mast); Cormac, Murray Gell-Mann, and W. Brian Arthur in 2006. (image: Laura Ware); Cormac plays guitar at Cowan Campus in 2018. (image: Laura Egley Taylor)

"... the true heir to Melville and Faulkner."
—Harold Bloom, literary critic.

Cormac McCarthy, novelist, SFI Trustee and Life Fellow, colleague, friend, inspiration, and one of the greatest American novelists, passed away on Tuesday, June 13, at his home in Santa Fe, New Mexico. He was 89 years old. Known for his award-winning books *The Orchard Keeper*, *All the Pretty Horses*, *Blood Meridian*, and *The Road*, McCarthy had a voracious mind and near-infinite interests. He befriended SFI through Murray Gell-Mann, a Nobel laureate in physics and Co-Founder of the Santa Fe Institute. He made SFI his second home, exchanging ideas with scientists and scholars and writing on his Olivetti manual typewriter. He wrote SFI's Operating Principles, and also became its Lifetime Trustee and Senior Fellow of the Institute. His last novels, *The Passenger* and *Stella Maris*, delved into the ideas of mathematics, physics, and analytical themes he explored with his colleagues at SFI.

"Today feels to me like a terrible disaster where many of us lost a good friend, the Santa Fe Institute lost one of its finest minds, and the world has lost one of its greatest authors," says SFI President David Krakauer. "Cormac refuted through his life and work the pettifogging myth that one cannot be both broad and deep. He read everything, he could sing and play a folk song after a single listen, he loved a well-tailored suit, he designed houses for his friends, he tortured himself with the philosophy of mathematics, and he schooled me in the geometry of the ideal bookshelf. Not sure what to make of the world without him in it."

James Hartle

James Hartle, External Professor at the Santa Fe Institute and Professor of Physics Emeritus at the University of California, Santa Barbara, passed away on May 17 at the age of 83. Until the end, he was passionate about physics and continued to work on the problems that were his life's work: the origin of the universe, how can quantum mechanics be applied to cosmology, and how to ensure that theories accurately model physical observations.

Often called the father of quantum cosmology, Hartle published landmark papers in the field of theoretical physics with people like Murray Gell-Mann, Stephen Hawking, and Kip Thorne. His relationship with Gell-Mann, one of SFI's Co-Founders, led to Hartle becoming a frequent visitor at the Institute and, in 2006, a member of SFI's External Faculty.

James Hartle and Murray Gell-Mann, longtime collaborators and close friends, in discussion at SFI. (image: InSight Foto)

Sean Carroll, who worked as a postdoc under Hartle and is now an SFI Fractal Faculty member, recounts the huge influence Hartle had on his life. "He provided a role model of a thoughtful, creative, deep-thinking scientist. He always worked on problems that he thought were the important ones, regardless of what others might have thought. And he was able to make progress on seemingly intractable issues because of the enormous care with which he approached any issue. He was an exemplar of what a physicist should be, and the field is much poorer with his passing."

David Krakauer, President of SFI, recollects that "Jim's brilliance, humor, and imperturbability seemed to make him immune to the usual slings and arrows of outrageous fortune. I cannot think of anyone else who could have worked as closely and as long as Jim did with Murray Gell-Mann and retain such good cheer. Jim's science is recorded not only in the long list of his own remarkable papers and books, but in his extraordinary collaborations that have contributed to a greater understanding of the universe."

James Pelkey

James Pelkey, former member of the SFI Board of Trustees, passed away on February 16, 2023, at age 77. A committed supporter of SFI research, Pelkey served on SFI's Board of Trustees for a decade, and became the Chair of the Board from 1990–1992. He was instrumental in acquiring the property for SFI's Cowan Campus.

Pelkey was driven by questions of how technological innovation could become economic growth. He wanted to understand whether there was a general principle underlying the emergence and evolution of information-based companies and if the process could be made more efficient and effective. Pelkey's search led him to SFI's work on economic theory and, eventually, to joining the Board.

James Pelkey served on SFI's Board of Trustees for a decade, and became the Chair of the Board from 1990–1992. (image: Walter Fontana)

Pelkey enjoyed attending SFI's research workshops. He engaged closely with the scientists, took great interest in the ideas they pursued, and often hosted long discussions at his Santa Fe home.

"He was intellectually and emotionally invested in the Institute, approaching his time as Chair like a quintessential entrepreneur: a pragmatic alchemist who binds together human and economic capital through vision for the purpose of creating reality," says Walter Fontana, Professor of Systems Biology at Harvard Medical School.

In a decades-long project, Pelkey documented the birth of industries and the Internet's evolution. First published online in 2009, his project launched in 2022 as the book *Circuits, Packets, and Protocols: Entrepreneurs and Computer Communications*.

"Jim had a deep enthusiasm for SFI's mission and people at a critical time in SFI's history. He also had an amazing thirst for both gaining and contributing to knowledge, which resulted in him writing a history of the earliest days of the internet and computer communication," says John Miller, External Faculty and Chair of SFI's Science Steering Committee. "He was driven in this quest by an act of pure scholarship as he wanted to chronicle this history for future generations."

BEYOND BORDERS *(cont. from page 2)*

cities. And all organizations dedicated to understanding design in this larger, distributed sense have no choice but to accommodate very different styles of thought.

When Dieter Rams first presented his Ten Principles of Good Design in the so-called Tokyo Manifesto from the late 1970s, he included: innovative, useful, aesthetic, understandable, unobtrusive, honest, durable, environmental, and minimal. Many of these characteristics are the hallmarks of good theories and models. One might debate the general accessibility of understanding when it comes to mathematical theory, and yet understanding is the ultimate goal of all good theory, and not prediction, which is a truth litmus-test and closer to the domain of statistics.

By placing SFI between The Bauhaus and Bell Labs, I feel that our community of scientists, mathematicians, and artists comes into sharper focus. Our project is a radical one, which seeks to explore the frontiers of complex reality — the garden of machines, as it were — and emphasizes the precarious balance between individual iconoclasm, communitarian vision, and creative production. Let me leave the final expression of this notion to our friend and colleague Cormac McCarthy.

"The world you live in is shored up by a collective of agreements. Is that something you think about? The hope is that the truth of the world somehow lies in the common experience of it. Of course the history of science and mathematics and even philosophy is a good bit at odds with this notion. Innovation and discovery by definition war against the common understanding. One should be wary." (*Stella Maris*, 2023)

— David Krakauer
President, Santa Fe Institute

ACHIEVEMENTS

External Professor **France Córdova** was awarded an honorary doctorate from Yale University.

SFI Program Postdoctoral Fellow **James Holehouse** received an award for "best thesis in Mathematical and Theoretical Biology in 2022" from the European Society for Mathematical and Theoretical Biology .

External Professor **Wendy Carlin** was named a Fellow of the British Academy.

External Professors **Aaron Clauset** and **Tina Eliassi-Rad** were named fellows and External Professor **Daniel Larremore** received the Erdős-Rényi Prize from the Network Science Society. **Eliassi-Rad** also received the 2023 Lagrange Prize.

External Professor **Alison Gopnik** is the 2024 recipient of the David E. Rumelhart Prize from the Cognitive Science Society.

External Professor **André de Roos** received an award for "Outstanding paper in theoretical ecology" from the Ecological Society of America.

France Córdova

James Holehouse

Wendy Carlin

Aaron Clauset

Tina Eliassi-Rad

Dan Larremore

Alison Gopnik

André de Roos

72 HOURS OF SCIENCE *(cont. from page 2)*

project and see just how far the group can take it. "Success" might mean learning which formats work and which don't, deepening relationships among the postdoc community, and discovering ways to ask better questions.

"In the end, we put in a great deal of effort and we worked on something really, really cool," says Holehouse. "It was quite nice bonding — it's very different from seeing someone in a work environment. Just being able to see what other people's skills are made it worthwhile."

Holehouse and Cantwell anticipate the group will continue working on their questions about the science of the science of science. "Now we have a good idea and a much clearer path on how to answer it," Cantwell says. "Half the work in academia is coming up with the right questions and an idea of how to answer them."

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RESEARCH NEWS BRIEFS

A new paper by External Professor Pamela Yeh and colleagues explores how the lockdowns in the early months of the COVID-19 pandemic affected the behaviors of urban dark-eyed juncos. (image: Eleanor Diamant/Yeh Lab)

URBAN JUNCOS ARE LESS AGGRESSIVE WITHOUT HUMANS

The lockdowns during the COVID-19 pandemic — sometimes called the "anthropause" — created an unprecedented opportunity to observe how urban birds behave in their home environments when there are no humans around to disturb them. In a new paper published in *Animal Behavior*, External Professor Pamela Yeh (UCLA) and her co-authors studied the behavior of the dark-eyed junco, *Junco hyemalis*, which has recently colonized cities in southern California. They found that, during the anthropause in 2021, male juncos in urban Los Angeles sang less and were less aggressive in defending their territories against rivals when compared to their behavior in 2019.

Without human disturbance, new foraging and nesting sites likely became available for juncos. This sudden increase in environmental resources would have decreased the birds' need to aggressively defend their territories, reduced the number of physical confrontations with rivals (and resultant injuries), and saved energy for other tasks like feeding chicks. The authors conclude that movement and singing associated with territorial aggression are plastic behaviors that adult birds modify in response to changes in their environment.

Read the study "Behavioural plasticity and the anthropause: an urban bird becomes less aggressive" at https:// doi.org/10.1016/j.anbehav.2023.02.005

THE HUMAN COST OF GLOBAL WARMING

For thousands of years, humans have lived in a surprisingly narrow subset of Earth's available climates. In 2020, SFI External Professors Marten Scheffer (Wageningen University) and Tim Kohler (Washington State University), with others, described this "human climate niche" in a paper in *PNAS*. And as global warming progresses, they found, more and more people will be pushed out of that historic climate niche.

A recent paper in *Nature Sustainability* reassesses that niche and proposes an updated estimate of the real human cost of climate change and who will bear it. In the paper, Scheffer and co-authors found that climate change has already put some 600 million people outside our climate niche. Current policies have us on track to reach ~2.7C global warming by the end of the century, which would leave about one-third of humans outside the niche.

Read the study "Quantifying the human cost of global warming" at https://doi.org/10.1038/s41893-023-01132-6

STOCHASTIC THERMODYNAMICS IN CO-EVOLVING SYSTEMS

Information-processing systems such as brains and computers are composite systems, consisting of many separate subsystems that affect each other's dynamics as they co-evolve. That has major effects on the system's thermodynamic properties. In particular, the precise network of which subsystem affects others determines the thermodynamic properties of the overall composite system.

In a new paper for *Entropy*, SFI Graduate Fellow Farita Tasnim (MIT) and SFI Professor David Wolpert provide a detailed investigation of this relationship. They explore how the co-evolution of the subsystems affects the thermodynamic properties of the overall system, specifically the system's "entropy production," which determines the minimal energy required to run the overall system. Their investigation also derives new thermodynamic uncertainty relations for information flows among the subsystems, and strengthened "thermodynamic speed limits" that restrict how fast the overall system can change its state.

"In this way, our paper starts to extend the revolutionary new field of stochastic thermodynamics into a framework that can properly address the rich behavior of the truly complex systems in the world all around us," says Wolpert.

Read the study "Stochastic thermodynamics of multiple co-evolving systems—Beyond multipartite processes" at https://doi.org/10.3390/e25071078

TIT FOR TATTLING: COOPERATION, COMMUNICATIONS AND ALTRUISM

Altruistic behavior often comes at a personal cost, but there are also benefits. The person you help might return the favor directly — tit-for-tat. Or, people might talk about your good deeds, and reciprocity could come via a third party. In a recent paper in Evolution and Human Behavior, SFI Graduate Fellow Victor Odouard and former Applied Complexity Fellow Michael Price explore the communication systems necessary to sustain indirect reciprocity.

The authors propose three conditions that can maintain stable, truthful communication. First, norms should prescribe behaviors that are rewarded. Second, the communication system should be used for disseminating information about both the altruism of actions and the truthfulness of communication. Third, people can make mistakes — and those errors can create stability by introducing diversity. "As institutions, legal systems, and governments develop, the role of the third party, and therefore, communication, only increases," the authors write. "It is therefore vital to understand how a communication system maintaining all of this social information could possibly be stable."

Read the paper "Tit for tattling: Cooperation, communication, and how each could stabilize the other" at doi.org/10.1016/j.evolhumbehav.2023.06.002.

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