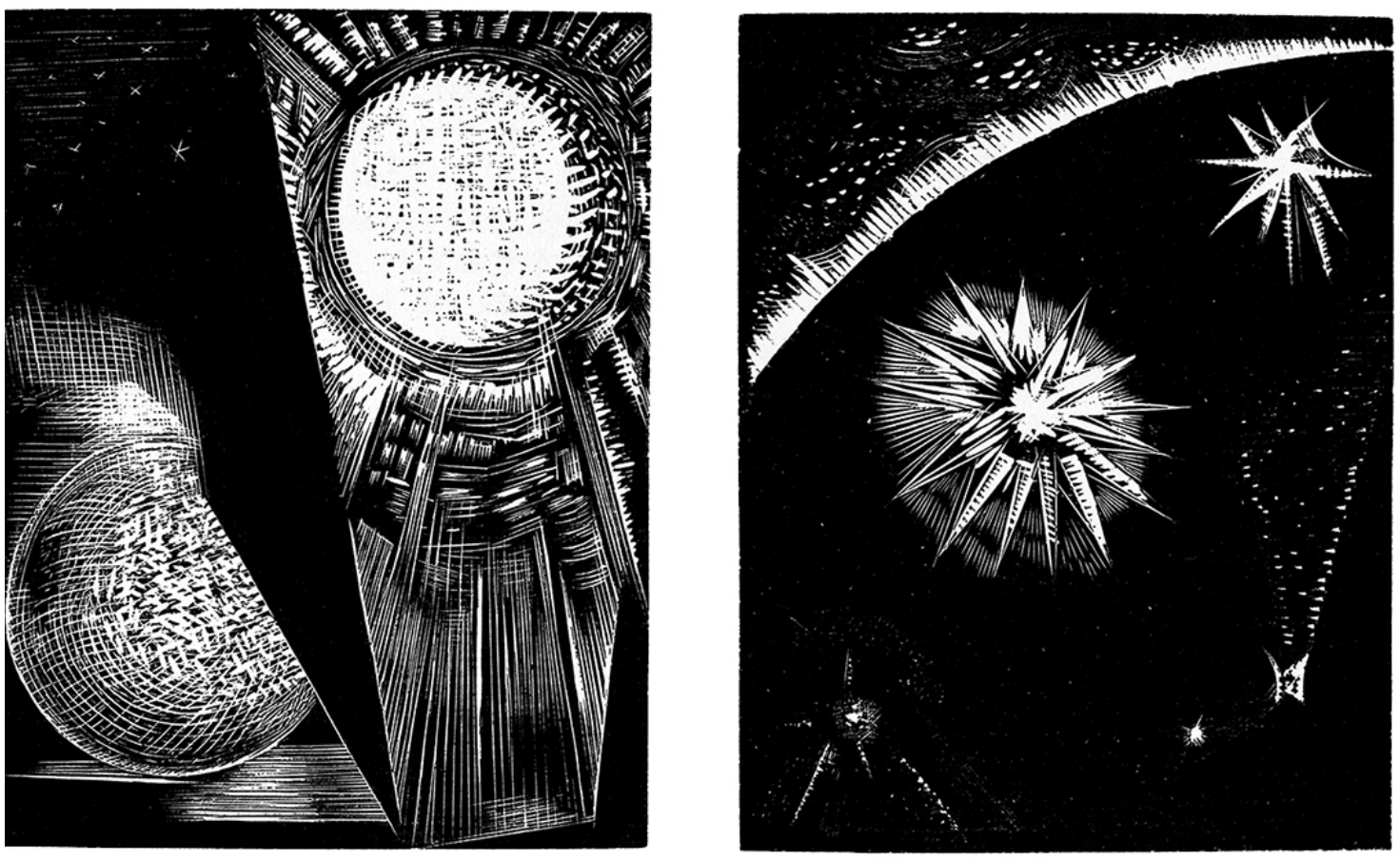
SUMMER 2025

Parallax

THE NEWSLETTER OF THE SANTA FE INSTITUTE



"The Sun and the Moon" and "The Stars Also." Woodblock prints from "Genesis" by Paul Nash, 1924. (image via Public Domain Review)

Exploring a science of history

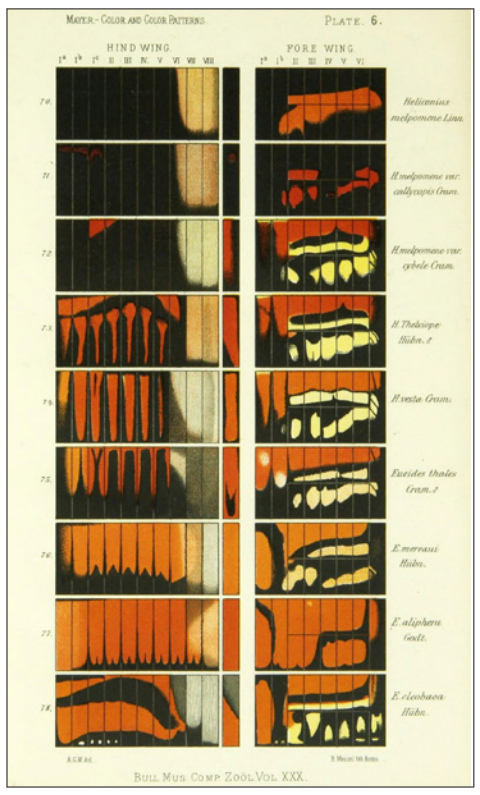
Historians might be considered the butterfly collectors of the past. Both groups are famous for launching into detailed descriptions of the particular — the complex factors contributing to the Roman empire's collapse, the camouflaging striations on a butterfly wing.

But butterfly collectors, and other naturalists, usually fit their findings into the overarching story of evolution. Meanwhile, historians tend to avoid making claims about larger patterns at work in historical human behavior.

"In history, we have scholars who are more interested in collecting and observing the particular than in creating models to fit the particular into bigger-picture explanations. We're so afraid of reductionism that we avoid risk-taking and ignore really interesting hypotheses," says SFI Fractal Faculty member Kyle Harper, a classical historian at the University of Oklahoma.

Inspired by conversations last year during an SFI working group on contingency and determinism, Harper co-organized a stand-alone meeting about the field of history.

That workshop on the "Science of History" was held at SFI June 16-18 and explored a series of provocative questions: How do laws and regularities in a domain like physics differ from those in human history? How might history be an evolutionary science? How does causation work in history? And finally, is it possible to define progress in human culture?



Historians, like naturalists, are famous for launching into detailed descriptions of the particular. (image: Plate 6 from Alfred G. Mayer's On the Color and Color-Patterns of Moths and Butterflies, *1897)*

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Measuring AI in the world

In the last few years, artificial intelligence has plunged out of the ivory tower. Now AI writes computer code, moves robots on command, drives cars, and even plays a role in hiring, housing, and criminal charges.

As AI deluges our daily lives, companies have run into a serious problem. Their longstanding tools for measuring AI performance and safety no longer suffice.

Last year, scientists at Google DeepMind posed a question: how do we evaluate AI models that are engaging actively with the world? It's a question that demands a complexity lens, says SFI Vice President for Applied Complexity Will Tracy.

"Because the deployment of AI involves so many complex-systems questions — about intelligence, institutions, society, human behavior, evolutionary transitions — SFI's Office of Applied Complexity is exploring this area over the next two years. By engaging with leaders on the front lines of AI development and deployment, we can promote complexity thinking and inform their understanding of these dynamic systems," he explains.

Tracy organized the "Measuring AI in the World" studio at SFI March 12–14. The Applied Complexity Studio Program brings leaders from industry, government, and civil society to SFI to examine far-reaching implications of complexity science on seemingly narrow industry problems.

Most frontier labs — companies at the forefront of building the world's most powerful and adaptable AI models — sent representatives to the studio. The gathering also included participants from governments, non-profits, and foundations working on AI.

Google DeepMind Principal Scientist William Isaac, Research Scientist Kristian Lum, and Staff Research Scientist Laura Weidinger served as co-organizers.

"I sincerely believe the convening at SFI will serve as a catalyst for this emerging area of research and practice over the coming years," says Isaac. "Given the cross-cutting, interdisciplinary nature of the topic, it could only have been held at a place like SFI. This expert group is pushing the frontier of the field and

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Stochastic thermodynamics, meet information theory

Ten years ago, SFI Professor David Wolpert set out to build a bridge between two scientific fields that might seem to have nothing to say to each other — computer-science theory and a branch of physics called stochastic thermodynamics. Computer-science theorists typically study the "resource cost" of computation — the number of iterations a computer requires to complete a calculation, for example, or the amount of memory needed. But, Wolpert says, there's also an important energetic cost in computing — how much energy is required — that has not been thoroughly investigated. Physicists who study stochastic thermodynamics, on the other hand, study systems far out of thermal equilibrium, which means they require or produce heat.

Wolpert recognized that computers operate far from thermal equilibrium: They require energy to run, and they produce heat as they do so. The mathematical tools of stochastic thermodynamics seemed like a perfect and obvious way to probe the energy dynamics of computations. "It was such a match made in heaven," he says. He assumed that this intersection had already been thoroughly explored, but he was wrong. So, he set out to establish the fundamentals on his own and convince others to join him. "I knew it would probably take about a decade before the engine would really start turning over."

A decade has passed, and he says the engine is humming. From June 16 to June 20 at SFI's Cowan campus, Wolpert and his SFI co-organizers hosted a working group — a follow-up to one held last year — that brought together researchers to explore ideas and forge collaborations between the two fields. Participants included computer scientists and physicists, representing three continents, who shared progress on existing projects, ideas for new ones, and brainstormed ways to forge the new mathematics required to explore fundamental ideas around the thermodynamics of computers. They're lured into the field, says Wolpert, by the possibility of developing new mathematics.

"We have no idea what's coming next," he says. The nascent collaborations could spin off in

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BEYOND BORDERS

PREQUELS, CLASSICS & SEQUELS

Herman Melville's 1849 novel *Mardi* has been described as a metaphysical sequel to Jonathan Swift's *Gulliver's Travels* and an inscrutable prequel to his own *Moby-Dick*. The first comparison suggests a derivative work, and the second a subordinate one. *Moby-Dick* is considered the "classic" work — a term that, according to Italo Calvino in his book *Why Read the Classics*, is "given to any book which comes to represent the whole universe, a book on a par with ancient talismans" and "the more we think we know them through hearsay, the more original, unexpected, and innovative we find them when we actually read them." In his book *Transcendental Style in Film*, Paul Schrader, for whom classic films are "more edifying and more permanent," made similar remarks.

Classics stand apart from and above their contemporaries, ancestors, and descendants. When it comes to pictorial art, music, nonfiction, and certainly science, we often speak of classic works, but we are less accustomed or inclined to speak of prequels and sequels. There is a world more attuned to historical currents where special relativity would be called a prequel to general relativity, Charles Darwin's *The Descent of Man* would be called a sequel to his *On the Origin of Species*, gene editing with CRISPR a sequel to ideas in evolutionary genetics, and gene regulatory networks a sequel to cybernetics.

If a prequel simply refers to preceding work that finds itself realized in a classic work, this is surely a widespread feature — and even a requirement — of all domains of inquiry. And if a sequel is the continuation of an idea or narrative, then this might be expected to be even more common. When it comes to the reluctance to speak of prequels and sequels in scientific ideas, several skeptical possibilities suggest themselves:

1. There are so few classics in science that to speak of sequels and prequels would be a kind of hopeful thinking, like describing the plains as the foothills to the prairie.
2. Classics are *sui generis* and severed from both the past and future. It is better to describe previous work as "preparatory studies" and subsequent work as "inspired by."
3. The progress of science is a collective wave, not a solitary particle, and to speak of prequels and sequels would lead to a collapse of the conceptual wave function and is therefore purely an artifact of observation.
4. There is an implicit immodesty in the idea of a prequel and a sequel that borrows gravitas both backward and forward from a focal work that does not deserve to be called a classic.
5. Every scientific work is so original that it lives in a space dense with singularities fragmenting all paths through time.

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Finding geometry in the humanities

Giambattista Vico, in his foundational treatise *The New Science*, argued that humans can only truly know that which we have made ourselves. Language, art, literature, religion — these cultural elements are how humanity best understands itself. Writing in 1725, Vico refuted the scientific thinkers of the time — René Descartes, foremost — who argued that knowledge derives from rational deduction.

Now, four centuries later, a cross-disciplinary group of mathematicians, computer scientists, and humanists are flipping the script on Vico's full-throated defense of the humanities, or at least splitting the difference. Cheekily titled "The New New Science," an SFI working group scheduled September 15–18 will address what it means to view the humanities as subjects described by — and understood through — mathematical and computational concepts. The meeting will explore how digital representations of knowledge offer new ways of thinking about the humanities.

"Vico titled it *The New Science* because he saw it as a new way to approach the study of history," says SFI External Professor Daniel Rockmore (Dartmouth College), one of the meeting's co-organizers. "We are working broadly from the same impulse: to create a new approach that brings mathematics to bear on non-mathematical subjects."

Although much of that which we call "the humanities" are intrinsically non-mathematical, as they are converted into digital forms, they take on numerical profiles that can be interrogated mathematically.

For instance, a recent paper by co-organizer Barak Sober, a Senior Lecturer of Statistics and Data Science and Digital Humanities at Hebrew University of Jerusalem, explored the social dynamics of the Hebrew Kingdoms during the Iron Age II by statistically analyzing ancient names recorded in archaeological excavations.

> "A book, transformed into a data cloud, turns into something with geometric meaning."

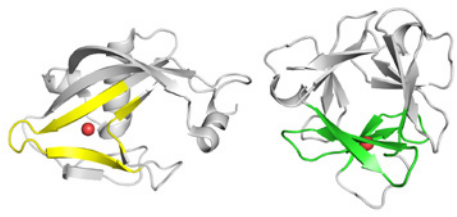
In another study, Rockmore developed a computational technique to authenticate works of art from digital scans of the original works.

The working group will convene scholars from both the sciences and humanities. Each day will feature a "Math 101" session — for example, a look at probability and statistical inference — and time for a humanist response to the lesson. The meeting structure is designed to introduce fundamentals of math and computer science into the humanities.

Rockmore and Sober, along with fellow co-organizer Renana Keydar, Associate Professor of Law and Digital Humanities at Hebrew University of Jerusalem, hope the working group is the first in a series of several meetings on the topic. Other desired outcomes from the meeting include a collected volume of essays featuring contributions from meeting participants, a white paper, and a journal article in an interdisciplinary journal.

"Large language models like ChatGPT and Claude transform words into vectors with hundreds, thousands of dimensions," says Rockmore. "A book, transformed into a data cloud, turns into something with geometric meaning. How can we ask new questions of culture in these new forms?"

Assembling the hidden rules of proteins



Proteins. (image: adapted from fig. 3 in "Evidence for the emergence of β-trefoils by 'Peptide Budding' from an IgG-like β-sandwich" Longo et. al., PLOS Computational Biology, 2022.)

The machine-learning model AlphaFold transformed the study of proteins, predicting folding patterns faster and more accurately than humans ever have. But it has done little to elucidate protein history.

"The origin of proteins was very complex. That great complexity surely did not spring into being like Athena from the brow of Zeus, out of nothing. But with current methods, we can't see the causal dynamic that made proteins possible," says SFI External Professor D. Eric Smith, a researcher at the Earth-Life Science Institute (ELSI) in Japan.

Smith has co-organized a working group looking for hidden rules that underpin proteins. "Assembly Theory for Folded Matter" brings molecular biologists, bioinformaticians, statisticians, machine-learning experts, and others to SFI August 18–21 to explore how proteins emerged, how they could evolve in the future, and how we might build new ones for medical treatment and beyond.

A key meeting pillar is that to truly understand proteins, you must search for underlying principles in all "folded matter" — any macromolecules that display folding, including polynucleotides and some polysaccharides.

"Molecular biologists studying the history of a fold traditionally think about repetition within one protein family. It's hard for us to systematically consider connections in a more global space: how is this fold a reuse of widespread forms, and what does that tell us about its generation or discovery?" says Liam Longo, a meeting co-organizer and researcher at ELSI.

To interpret reuse across folded matter, working-group participants will apply the tenets of assembly theory, developed by SFI External Professors Sara Walker (Arizona State University), Lee Cronin (University of Glasgow), and their labs. Organizers hope to determine if the theory, built to explain the biochemistry of small molecules, also fits larger macromolecules. If it does, that could have major implications for activities such as developing new drugs, where approaches for small molecules like aspirin and large folded proteins like antibodies can differ.

"Assembly theory centers on a quantitative measure of complexity that asks, what is the shortest path to make an object where you can reuse pieces you made along the way?" says co-organizer Cole Mathis, an assistant professor at Arizona State University. "With this working group, we're asking how that measure holds up against a new physical system, and what it reveals about the deep history and future evolution of proteins."

Participants will also probe how machine learning-methods can spot repeated forms and clarify the balance of invention and reuse as proteins evolved.

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Chaos in the machine

Until recently, using machine learning for a specific task meant training the system on vast amounts of relevant data. The same was true for data representing a system that changes over time, says SFI Complexity Postdoctoral Fellow Yuanzhao Zhang. "The traditional paradigm in forecasting dynamical systems has always been that you need to train on the system you want to predict," he says. If you want to forecast the weather in Santa Fe, start by training your model on the area's historical weather data.

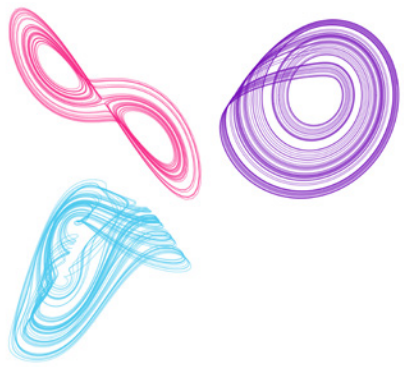
But the advent of *foundation models* — a term coined in 2021 to describe the architecture at the heart of today's AI systems — has changed the game. These models, like previous systems, train on large datasets. But unlike earlier, specialized deep-learning models, they're designed to carry out a wide range of tasks. "They work right out of the box," Zhang says. Notably, they can complete new tasks that weren't included in their training data. For large language models, those include tasks like generating computer code or translating between languages. Reports of this behavior, called "zero-shot learning," ignited a global race to build models that can similarly make zero-shot predictions for time-series data.

Zhang wanted to understand whether existing foundation models could predict chaotic systems and, if so, how they do it. In a recent analysis, Zhang and William Gilpin, a physicist at the University of Texas at Austin, reported that a foundation model called Chronos could generate predictions of chaotic dynamical systems at least as accurately as models trained on relevant data. Their paper was accepted to the 13th International Conference on Learning Representations, which focuses on deep-learning approaches in AI, and which was held in Singapore in April 2025.

Zhang says the paper represents the first test of zero-shot learning in forecasting chaotic systems, such as the weather and financial markets, which are governed by mathematical equations and extremely sensitive to small changes in initial conditions. Zhang and Gilpin tested their idea by using Chronos to predict how 135 chaotic systems would change over time. They tested each system using 20 distinct initial conditions. They compared the short- and long-term predictions of the model to deep-learning models specifically trained using chaotic data.

"We wanted to compare this zero-shot paradigm with the old paradigm to see if the foundation model can outperform the traditional models," Zhang says.

The promising results show that foundation models can make accurate predictions after training on data from *any* time series — not just data from the system or task that a user wants to predict. Forecasting the weather in Santa Fe may not require historical data, just other time-series behaviors in which the model could identify patterns.



Chaotic attractors with fractal geometry are hard to forecast due to sensitivity on initial conditions. (image: adapted from fig. 1 in Zhang et. al. 2025)

The study raises interesting ideas about what kind of training is required to accurately perform time-series tasks. "There's this question: Do you actually need to learn chaos to have a good forecasting performance for chaotic systems?" Zhang asks. "I think the answer is no."

Zhang and Gilpin's current work only looks at one-dimensional data; in future work, Zhang says he hopes to expand that to more complicated, multidimensional data. He'd also like to determine how the system carries out these tasks. "Is it, in some sense, learning the dynamics?" he asks. "Is it using anything more sophisticated than parroting?"

The new study offers a step forward in answering those larger, deeper questions, he says.

SFI Board of Trustees names Chair & Vice-Chair

[L-R] Sam Peters and Ian McKinnon during SFI's 2025 Spring Symposium. (image: Kate Joyce)

This spring, the Santa Fe Institute's Board of Trustees elected Ian McKinnon and Sam Peters as Board Chair and Vice-Chair. McKinnon and Peters, who both grew up in New Mexico, have multi-decadal relationships with SFI. Their three-year appointments began on April 29, 2025, following the Board's bi-annual meeting.

Ian McKinnon was first introduced to the Santa Fe Institute in 2007 by investors Bill Miller (SFI Life Trustee and Chairman Emeritus) and Michael Mauboussin (SFI Trustee and Chairman Emeritus). SFI's transdisciplinary approach felt like an immediate fit. "Complexity offers an extraordinary prism to look at phenomena in the world, at emergent behavior, and particularly at markets, which had been the center of my life for so long," he says. "The fact that all of this cutting-edge, fundamental research was taking place in New Mexico, the state where both my wife, Sonnet, and I were raised, was incredibly meaningful."

He joined the Board in 2013, became the Board Vice-Chair in 2021, and, with Sonnet, has made multiple large gifts to SFI to support education and to expand fundamental research and core science. They also underwrite the highly popular free Community Lecture series at Santa Fe's Lensic Performing Arts Center, bringing engaging, accessible talks about complexity science to a wider audience.

McKinnon, who founded Sandia Holdings, LLC, a family investment firm after he retired from Ziff Brothers Investments, says that engaging with ideas about complexity at SFI influenced his work as an investor in two discrete respects. In the first, pedagogy about power-law distributions has refined his thinking about investments and how different companies grab market shares. In the second, conversations with novelist and Trustee Cormac McCarthy and SFI President David Krakauer about the unconscious mind have helped him embrace the deep work our minds can do when we're not focused on a problem. "If I'm really worried about something, I'll think about it before I go to sleep, intentionally tapping into the subconscious," he says.

As he steps into the role of Board Chair, McKinnon acknowledges the foundation built by those who have held the role before him. "The past two Chairs, Michael Mauboussin and Katherine Collins, did a phenomenal job. It's a formidable challenge even to maintain pace, but that's part of what excites me," he says. "As Vice-Chair, I served side-by-side with Katherine as a partner on many tactical issues. It's a great way to operate, and it's how I plan to work with Sam."

Sam Peters, whose first encounters with SFI began when he was a teenager, has been an active supporter of the Institute for more than 30 years and a member of the Board since 2013.

In the late 1980s, before the Institute had found a permanent home, SFI co-founder George Cowan invited Peters' Tesuque-based family to the Cristo Rey convent to allay his mother's concerns about the nascent research organization. A few years later, fresh out of college, Peters heard how SFI had shaped the intellectual journey of investor Bill Miller, who would later become his boss. "It crystallized my interest in investing and powerfully combined it with a complexity framework that has guided my development as an investor ever since," says Peters. He read M. Mitchell Waldrop's *Complexity* — a 23rd birthday gift from his mother — and knew at that point he wanted to be an SFI insider. "I did not think the opportunity would emerge," he says. "Fortunately, it did."

> "One cannot overstate the synergy that results from working with deep thinkers . . . who share a vision for SFI . . .that is highly exploratory, risk-oriented, and rigorous to its very atoms."

Through graduate school, he began to meet other people connected to SFI — Katherine Collins, Michael Mauboussin, and later, Ian McKinnon — who shared an intense interest in complexity. "As a Bayesian statistician, I know that information-rich environments are those that challenge existing prior beliefs, to the degree that they must be updated," says Peters. "This updating of beliefs is true learning. Nothing has moved or continues to challenge and evolve my beliefs like SFI."

Peters, now a managing director at ClearBridge Investments, says he has watched SFI "reach escape velocity" and finds it incredibly satisfying to be part of a Board that supports this momentum. "David and the team have brought a level of energy and creativity that I have not observed in any other affiliations," says Peters. "I couldn't be more honored to support SFI and my fellow New Mexican and long-time friend Ian as Vice-Chair. Ian is an incredible person and teacher, and my goal is to help him further enhance the support the Board can provide to David and the SFI team."

Along with McKinnon and Peters' election to Chair and Vice-Chair, the Board announced a renewed five-year contract with SFI President David Krakauer. "With that agreement in place, we can focus on other questions, like what new areas of science or geography we might explore, or which thought leaders we want to bring to campus," says McKinnon.

Krakauer, who is also the William H. Miller Professor of Complex Systems, says he is excited to be working with McKinnon and Peters in their new leadership positions.

"I am delighted that Ian and Sam have assumed positions as chair and vice chair. One cannot overstate the synergy that results from working with deep thinkers who are not only friends, but colleagues, who all share a vision for SFI," says Krakauer. "An SFI that is highly exploratory, risk-oriented, and rigorous to its very atoms. The Board of Trustees at SFI, like nowhere else I know, is an integral part of the community and very often the most vocal champions of complexity science. And Ian and Sam are exemplary in this regard. I count our whole community as very fortunate."

HIDDEN RULES OF PROTEINS *(cont. from page 2)*

"We've reached a moment when the three meeting pillars — machine learning, assembly theory, and the concept of folded matter — can now make more concrete progress together than they can individually. Building on SFI's long history of developing biological theory, this working group may help create a theoretical framework for a crucial element of the origin of life," says co-organizer and ELSI researcher Harrison Smith.

The organizers hope to launch a continued partnership between SFI and ELSI, new research topics that would be reasonable in scope and timeline for a Ph.D. student or postdoc to tackle, and a network of interdisciplinary collaborators.

ACHIEVEMENTS

SFI External Professors **Alison Gopnik** (UC Berkeley) and **Scott Page** (University of Michigan) were elected to the National Academy of Sciences.

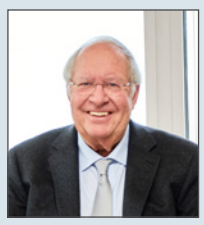
Alison Gopnik

Scott Page

Mason Porter

External Professor **Mason Porter** (UCLA) was elected to the Network Science Society.

SFI Life Trustee and Chairman Emeritus **Bill Miller** was elected to the American Philosophical Society.



Bill Miller

Kaleda Denton

Complexity Postdoctoral Fellow **Kaleda Denton** has been recognized by the European Society for Evolutionary Biology as the runner-up for the 2025 John Maynard Smith Prize for outstanding young biologists.

External Professor **Mahzarin Banaji** (Harvard) received a BBVA Foundation Frontiers of Knowledge Award in Social Science.

Mahzarin Banaji

Anna Clemencia Guerrero

Complexity Postdoctoral Fellow **Anna Clemencia Guerrero** received a Whitman Center Fellowship from the Marine Biological Laboratory.

Cultural-transmission models for the modern day

Holga 120 Lomography double exposure of NYC and the Brooklyn Bridge. (image: Sandy Hibbard/Unsplash)

Traditional models of how culture spreads were designed to describe early civilizations, typically focusing on hunter-gatherers and almost always on pre-industrial societies. Today, a myriad of factors — from the internet to our highly diverse societies to astonishing levels of inequality — shape the way cultural norms are transmitted. The old models of cultural evolution simply don't describe today's societies.

To begin building an updated framework of modern-day cultural transmission, representatives from fields including anthropology, sociology, economics, and cognitive science gathered at SFI May 14–16 for a working group called "Building a Science of Cultural Evolution for the 21st Century."

"The set of problems in this field is vast," says SFI External Professor Paul Smaldino, a University of California, Merced, cognitive scientist who organized the event. Workshop participants proposed studying everything from concrete problems, like how fascism spreads, to more abstract ones, like how models can better capture the scale of today's complex societies.

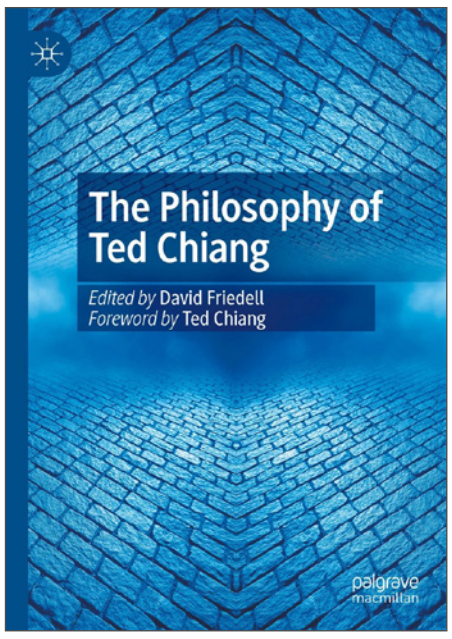
In some cases, scientists have starting points for this research. For example, the spread of opinions about healthcare, like whether or not to get vaccinated, can be at least partly captured by adapting models of disease transmission. In other areas, researchers are still grasping for a starting point. For example, they have very little understanding of what sparks creativity or of how new ideas arise from recombining old ones.

In this age of plentiful data, it's tempting to apply artificial intelligence to these problems, and "in the short term, that works amazingly well," Smaldino says. But AI assumes that the processes dictating cultural evolution remain the same over time, and sometimes that's a dangerous assumption. "In 2008, when nobody predicted the financial crash, that was partly because the models made assumptions that no longer held," Smaldino says. In the long-term, researchers need theoretical models of cultural change that allow for flexibility.

Workshop participants are already planning collaborations for the coming months and years, during which they'll pool their diverse expertise to develop modern-day models. With these tools, they hope to understand the forces driving cultural transformations seen across the globe.

This workshop was funded in part by the John Templeton Foundation.

Book Review: *The Philosophy of Ted Chiang*



The cottage industry of compiling philosophical essays about popular cultural artifacts began to grow in the early 2000s, with books like *The Simpsons and Philosophy*, *The Matrix and Philosophy*, and *Bob Dylan and Philosophy*. Yet the origins go back to Benjamin Hoff's 1982 bestseller *The Tao of Pooh*, which introduced readers to the more or less unfamiliar Eastern philosophical system of Taoism through A.A. Milne's familiar tales about anthropomorphic animals. While the appeal of these books is understandable, given that they make difficult philosophical issues more accessible and at the same time reveal greater depths beneath what otherwise might seem to be mere pastimes and entertainments, too many of the now hundreds of such titles feel forced, published for the writer's sake more so than the reader's. Do we really need *The Atkins Diet and Philosophy*, *The Red Sox and Philosophy*, or *Kiss and Philosophy*? Some cultural phenomena have nothing to do with the hard problems of human existence and are patently unphilosophical.

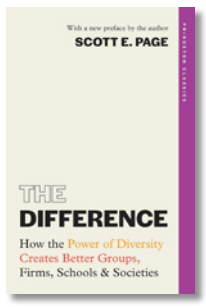
This past April, Palgrave McMillan published *The Philosophy of Ted Chiang*, edited by David Friedell. It is the rare welcome addition to the subgenre, in part because Chiang's science fiction is profound across many areas of philosophical inquiry — including questions concerning the nature of time, human consciousness, language, identity, and agency. It is made even more welcome by the inclusion of a foreword by Chiang himself, who admits that, while he does not set out to write stories that dramatize specific philosophical questions, he nevertheless turns to philosophy during the process of writing, the better to understand the nature of his own imaginative output. In the process of writing "Anxiety is the Dizziness of Freedom," for example, Chiang read Daniel Dennett's *Freedom Evolves* alongside Robert Kane's T*he Significance of Free Will*. Meanwhile, the title is a reference to Søren Kierkegaard's *The Concept of Anxiety*. "I clarified my own thinking about certain philosophical questions, but I can't say that was my original goal," Chiang writes, adding that "science fiction needs to be good art, and a certain amount of real science or real philosophy can help with that, but if pursuing absolute accuracy would interfere with the author's artistic goals, art should take priority."

Chiang, an SFI Miller Scholar who regularly contributes to meetings with his abundant knowledge of literary history, science, technology, philosophy, and art, is arguably America's preeminent science-fiction writer. This is another reason *Ted Chiang and Philosophy* is richer than so many other similarly titled volumes. The scientific foundations of his work allow the essay contributors to speculate not only about the perennial ethical, aesthetic, and epistemological themes his work popularly covers, but also about the problems that science increasingly presents for the philosophically minded: a philosophical outlook on Chiang's work carries with it a philosophical outlook on science. In essays like "We Can Remember It for You Better: Ted Chiang on Technology and Human Knowledge," and "Time Machines and Predictors are Possible but Unlikely," the authors allow us to glimpse how storytelling, technology, scientific conundra, and human identity are all delicately interwoven. Other essays, like "Existential Responsibility in Kierkegaard, Nietzsche, and Chiang," deal more strictly with questions of morality and the affirmation of individual human selfhood.

A worthwhile volume for devoted fans of Chiang's work as well as academic philosophers and laypersons in love with deep questions, and a notable exception to the publishing trend of over-philosophizing the non-philosophical, *The Philosophy of Ted Chiang* does some justice to the wonderful stories of one of our greatest living explorers of the human condition.

Review by SFI Research Fellow Tony Eagan

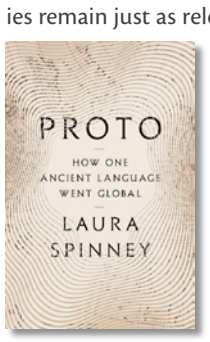
Other books published this spring



The Difference: How the Power of Diversity Creates Better Groups, Firms, Schools, and Societies

Scott E. Page, SFI External Professor (University of Michigan)
published May 13, 2025

Originally published in 2007, External Professor Scott E. Page's landmark book *The Difference* was republished this spring as a Princeton University Press Classic. Updated with a fresh preface, the book's original insights for groups, firms, schools, and societies remain just as relevant today.



Proto: How One Ancient Language Went Global

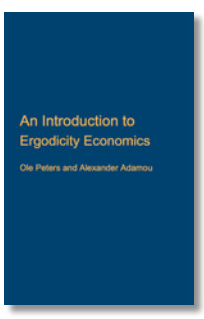
Laura Spinney, 2022 CSSS Journalism Fellow
published May 13, 2025

Daughter. Duhitár-. Dustr. Dukte. These words from English, Sanskrit, Armenian, and Lithuanian share both sound and meaning, with roots in a Proto-Indo-European language that died out thousands of years ago. Inspired by a conversation during her CSSS Journalism Fellowship in 2022, Laura Spinney traces the journey of this early language into its myriad descendants.

More Everything Forever: AI Overlords, Space Empires, and Silicon Valley's Crusade to Control the Fate of Humanity

Adam Becker, 2024 CSSS Journalism Fellow
published April 22, 2025

In *More Everything Forever*, science journalist Adam Becker investigates implausible and alarming tech-fueled visions of tomorrow. The book, which was months from publication during Becker's SFI Fellowship, draws on his physics background to show why there is no good evidence that these visions will come to pass.



An Introduction to Ergodicity Economics

Ole Peters, SFI External Professor (Oxford University) and Alexander Adamou
published June 1, 2025

Do we think of randomness as variation across time or as variation across multiple systems? This is the question at the heart of ergodicity economics, an idea Ole Peters has been exploring for the past 20 years. With a deliberate, systematic, and simple approach, this new textbook outlines the beginnings of a new field.

THE COLOPHON: UPDATES FROM THE SFI PRESS

Q&A with W. Brian Arthur

SFI External Professor W. Brian Arthur in conversation with SFI Press Managing Editor Sienna Latham in November 2024. (image: Cressandra Thibodeaux/SFI)

In 1987, the Santa Fe Institute was a fledgling startup, operating from an old convent on Canyon Road in Santa Fe. "Nobody was quite sure if it would take, like planting a delicate sapling and wondering if it was going to grow into a tree," says External Professor W. Brian Arthur. Following a successful meeting on the topic of economics and the subsequent publication of a groundbreaking book, *The Economy as an Evolving Complex System*, Arthur launched the Institute's first official research program.

Nearly 40 years later, complexity economics remains an enduring research theme at SFI. Two subsequent volumes of *The Economy as an Evolving Complex System* were published in 1997 and 2001. The SFI Press will soon release a fourth. Edited by a team of established and early-career scientists, including SFI External Professors Jenna Bednar (University of Michigan), Eric Beinhocker (Oxford University), and J. Doyne Farmer (Oxford University), the latest book considers the state of economics during a time of global turmoil — and looks toward the future from a complexity-science perspective.

This spring, the SFI Press team met with Arthur to discuss the Institute's role — and his own — in the development of complexity economics over the last four decades.

SFI PRESS: When and how did the economics program at SFI begin?

WB ARTHUR: We'd had a very important meeting in 1987 between economists and physicists; Kenneth Arrow was in charge of the economics group, and Philip Anderson was in charge of the physics groups. A year later SFI followed this by setting up its first research program, on the economy as an evolving complex system, and I was asked to lead it.

Early on I asked Arrow and Anderson, "What do you want our group to do?" They contacted John Reed, CEO of Citibank at the time, who was funding the group. The word came back, "Do anything you like, providing it is not conventional, and is at the foundation of economics."

SFI PRESS: How did you decide what to focus on?

WB ARTHUR: There were many possibilities. Chaos theory was popular at the time. So was nonlinear dynamics. So was increasing returns. I couldn't make a decision, nor could anybody else, but it was my job to come up with the theme.

Finally, Stuart Kauffman, a theoretical biologist, comes into the kitchen of the convent with a cup of coffee. He sits down and says, "Everything you guys do in economics is at equilibrium. Why is that? What would it be like to do economics out of equilibrium?"

I remember my reaction was bristlingly negative. I thought, "but economics *is* equilibrium!" I just shut Stuart up right away. Equilibrium was just so much in the DNA of the field by then. Equilibrium was God. But Stuart's question stuck with me — had I ever thought of that before? Not really. It was as if Stuart went in with a red-hot poker to the subject.

SFI PRESS: How did mainstream economics respond to the ideas being developed at SFI?

WB ARTHUR: With difficulty! We relaxed many of the conventional assumptions, and that was foreign, and different. A 1990 article I did on increasing returns in *Scientific American* made a lot of difference. People did start to notice, but I wasn't a member of the club, and Santa Fe people weren't members of the club. So, the field initially resisted these ideas; but I believe it has now opened up to them, and has taken much interest.

SFI PRESS: How was the term "complexity economics" coined?

WB ARTHUR: In 1999, *Science* magazine asked me to do an article on complexity and economics. So I did that, and the editor called me, and he said, "I like your paper, but you need to give this new approach a name." And I said, "No, I don't." And he said, "Yes, you do." So, he won the battle, and I remember standing in my apartment on what was called a landline — prehistoric! — and I said, "All right, if you insist, call it complexity economics." As luck would have it, that label took off.

This field could well be called nonequilibrium economics, which I had decided against early on in that conversation with *Science*, because it's like saying non-anything. Would you call general zoology "non-elephant studies"? It didn't do it for me to define something new in terms of the old.

For the latest updates on the fourth volume of *The Economy as an Evolving Complex System* and other books from the SFI Press, visit www.sfipress.org

STOCHASTIC THERMODYNAMICS *(cont. from page 1)*

many possible directions. Almost every issue of concern in computer-science theory can be translated into terms of energetic costs rather than other kinds of resource costs. Then, these issues can be dissected, analyzed, and modeled by developing new mathematical tools, using thermodynamics. Boolean circuits, for example, are mathematical models of computation that carry out logical operations — and operate far from thermal equilibrium. Researchers at the meeting discussed using stochastic thermodynamics to better understand the energy cost of big communication networks and chemical computers, which use chemical reactions to compute instead of the usual components.

"Basically, every chapter in computer-science-theory textbooks" is fair game, says Wolpert. "It's all happening." The meeting participants are already planning the next meeting and exploring possible publications and future books on the emerging subfield, as well.

"This is what SFI is all about," he says. "Taking fields that never even knew one another existed and just getting them to finally bump into one another near the punch bowl. That was this meeting."

Simple narratives on bias & political leanings fall short

Chicago, a Democratic stronghold, is just one of the cities that did not conform to common narratives about bias and political leanings in a recent study by SFI's Andrew Stier and Brandon Ogbunu. (image: Dr. Chris Stantz / Wikimedia Commons)

Nearly 40% of U.S. cities analyzed in a recent study in *NPJ Complexity* diverge from the common narrative that Republican-dominated areas have high levels of implicit racial bias while Democratic strongholds have less.

Led by Complexity Postdoctoral Fellow Andrew Stier, the study combines prior research on implicit racial bias — people's unconscious attitudes and beliefs about race — with voting data from the 2016 and 2020 presidential elections across 146 U.S. cities.

Instead of neatly dividing along party lines, the study paints a patchwork picture, revealing 58 cities where political affiliation and racial attitudes reflect local culture and lived experience more than partisan expectation.

"We found many exceptions to the common narrative," Stier says. "This reflects what many people experience. In some Southern cities, you might meet people who are kind to individual people from different racial or ethnic groups, yet still vote for discriminatory policies. Meanwhile, there are places that feel more interpersonally exclusionary but vote for inclusive policies."

Cities like Knoxville, Tennessee, and Spokane, Washington, voted Republican but showed lower-than-expected levels of implicit racial bias, once factors like diversity, segregation, and city population were accounted for. In contrast, Chicago, Illinois, Albany, New York, and Minneapolis, Minnesota, all Democratic strongholds, exhibited higher-than-expected bias levels.

The idea for the study began with an informal conversation between Stier and co-author Brandon Ogbunu, an SFI Resident Professor and evolutionary biologist at Yale University, at SFI's Complexity Global School last summer in Bogotá, Colombia. They noticed that many patterns in the data didn't match the common narrative about the link between racial attitudes and political identity.

"What stood out to me was how closely the data mirrored things I've experienced first-hand — things that don't always show up in national narratives," Ogbunu says. "They reflect the kind of social dynamics that we often sense but rarely see captured in research."

Rather than looking at overall bias levels, the researchers adjusted for city size, diversity, and segregation. By removing these structural effects, they focused on what remained — subtle signals that may reflect a city's cultural norms and everyday social dynamics.

"There's a temptation to tell simple stories about political identity and race," Stier says. "But the truth is much more complicated — and that complexity matters if we want to really understand how attitudes and behaviors shape our democracy."

Next, the researchers plan to extend their analysis using 2024 election data and explore other forms of bias, including gender and age.

"Cities are complex systems," Ogbunu says. "If we want to understand what shapes a place's political and cultural climate, we have to look beyond easy assumptions and start embracing that complexity."

SCIENCE OF HISTORY *(cont. from page 1)*

"This is a new version of a conversation that's been going on for at least 20 years at SFI about the relationship between historical sciences, paleontology, evolution, archaeology, and history. How do you develop laws and generalities for historical disciplines writ large?" says co-organizer and SFI External Professor Doug Erwin, a paleobiologist.

A more scientific history would follow in the footsteps of many disciplines that worry about the complicated relationships between the particular and the general. "For 100 plus years, paleontology was a highly descriptive, almost narrative approach to science: What's the fossil? Where did you find it? How is it preserved? It was almost as particularist as history is now," says Erwin. "But in the 1980s and '90s, the paleobiological revolution started asking larger and much more quantitative questions."

However, philosophers at the SFI workshop put pressure on the idea that a science of history could even exist. "If historians try to bring in too much science, it may squeeze out the question of human freedom," says workshop co-organizer and SFI Research Fellow Tony Eagan. "That's a problem, especially for historical inquiries that consider governance and how social life, culture, and the state are best organized. I appreciated that the meeting tried to define not just history but also science, and how big their Venn diagram really is."

The workshop addressed how historians have turned away from the sciences and even the social sciences, says UCLA professor of modern European history Lynn Hunt, who spoke at the workshop about changes in the field of history over time and the place of the digital humanities. "Historians have been nervous about how supposedly scientific perspectives can be used to nefarious political ends. There's an inbred suspicion that science will be used to justify inequalities, instead of being used to study how we get inequalities," she explains.

Hunt found the SFI meeting a step in the right direction to foster more productive collaboration between scientific and humanistic researchers. "Existing digital humanities efforts usually focus on digitizing as opposed to analyzing. They have not fully encouraged humanists to apply other kinds of models to all this wonderful data that is being collected," she says.

Philosophers like Michael Strevens of New York University found it useful at the workshop to explore the limits of a science of history.

"On a busy street in New York City, people don't bump into each other because they adapt their movements to be regular and predictable. These regularities are common in human behavior," Strevens says. "But what happens when people use their faculties not to make things regular, but to create something truly revolutionary or even catastrophic? Think about the panic that might occur in a financial crisis, or the enthusiasm for change that might lead to a political revolution. Human agency can make such things very hard to predict."

> "To get at foundational issues about what history is, you need perspectives from complex-system science and from evolutionary biology."

The mix of historians, archaeologists, sociologists, biologists, philosophers of science, physicists, and complexity scientists at the workshop proved fruitful, provoking the kinds of conversations that can push history to move beyond merely collecting metaphorical butterflies, and actually integrate data into a wider view. Participants have already started arranging further collaborations.

"To get at foundational issues about what history is, you need perspectives from complex-system science and from evolutionary biology," says co-organizer Harper. "At the workshop, we tried to tackle a profound question: How do we think about our own past? We need to grapple with the question of culture and the uniqueness of the human chapter of evolutionary history — while at the same time seeking continuities with the long evolutionary past, as well as with deep principles of complexity that span various adaptive systems."

This event is supported by the James S. McDonnell Foundation Grant Number 220020491, Adaptation, Aging, and the Arrow of Time. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the James S. McDonnell Foundation.

MEASURING AI IN THE WORLD *(cont. from page 1)*

solidifying the core intellectual questions for the next few years, especially as AI systems move into the real world in critical domains."

SFI researchers discussed how to gauge the impact of AI from unexpected angles, focusing on a complex-systems approach.

"We live in algorithmically infused societies, where the algorithms are based on AI technology. To measure the impact of AI on society — its risks and its rewards — we must adopt the mindset of complexity researchers," says SFI External Professor Tina Eliassi-Rad (Northeastern University), who spoke at the event. "At the studio, we discussed the importance of measuring the impact of feedback loops, non-equilibria, and self-organization on human–AI ecosystems. All are important concepts from complexity science."

> "Extraordinary claims require extraordinary evidence. We need to pull back the claims, or find ways to make new types of quantitative measurements."

SFI researchers covered topics such as the psychology of human intelligence, challenging the popular idea that frontier AI possesses a robust world model. Another presentation suggested that lessons from evolutionary transitions in both cities and organisms could inform our understanding of AI's impact.

"The field of AI has made the biggest, most grandiose claims first — for example, 'this large language model is already conscious.' But we don't yet have a complete science of animal consciousness!" says SFI Professor Chris Kempes. "During the studio, I pointed out that extraordinary claims require extraordinary evidence. We need to pull back the claims, or find ways to make new types of quantitative measurements."

Frontier lab representatives say the studio led to tangible progress on the AI-measurement dilemma. "Evaluation — long considered a solved issue in machine learning — is now one of the central challenges in modern AI," says participant Maximilian Nickel, a scientist at Meta AI. "The SFI studio was a great success, advancing not only our understanding but also fostering a vibrant community around a critical epistemic question: how can we truly know how good our models are?"

To continue exploring that question, some participants reunited this summer in London at an ACtioN Roundtable discussion, again co-hosted by Google DeepMind and SFI. Held within DeepMind's global headquarters, the June Roundtable used complexity science to organize a discussion of AI's possible impact on social and economic distributions. Discussion ranged from how science gets done to which sectors will see the most labor disruption, and how education will need to evolve.

BEYOND BORDERS *(cont. from page 2)*

This list of extremes is rather obviously tongue-in-cheek. Considered more carefully, they can be transmuted into five more serious variations, some of which might seem to be contradictory, but which capture a few real, increasingly salient tendencies in contemporary society and in contemporary scientific institutions that reflect a shunning of history and contingency.

1. The argument in some quarters that science is, like all other pursuits, merely a matter of contemporary opinion — opinions that vary in amplitude and not in verisimilitude.
2. Research metrics, having been built around a winner-takes-all mechanism, foster the idea that only a small number of papers matter — a sort of preferential attachment version of the Carlyle theory of heroes — where the winner takes all.
3. How the justified concern with fairness and broader recognition of teamwork (a counter to point 2) can inadvertently generate group think, excluding the possibility that sometimes an idea needs solitude to be incubated before emerging into the light of day.
4. The desire to spot the patterns of influence can obscure the revolutionary nature of an idea by situating it in a period of normal science.
5. The obsession with prizes, which tend to reward those who have already been overcompensated, can narrow the mind to the synthetic reality of concepts.

Ideas are built on ideas that have been tested against reality, not against the "Like" button. Popularity is the flimsiest proxy for the truth, and long-term influence speaks a very different language than the language of influencers. Recognition of the importance of collective intelligence should not diminish the process of alchemy undertaken by single minds, whose greatest prize is to become a part of collective intelligence. Harold Bloom in his *Anxiety of Influence* described the complex relationship that all work has with the past and the future in terms of "revisionary ratios" or the balance of following and swerving, which recognizes how achievement is always part reaction and part revolution.

We should learn to be more comfortable with prequels and sequels, which are honestly what most of us produce most of the time. There is even the word "interquel," which can describe the incremental fractions of progress that typify serious research work, and the optimistic idea of the "paraquel," or magical moment, when many ideas spring into existence together.

— David Krakauer
President, Santa Fe Institute












SUMMER SCENES AT THE SANTA FE INSTITUTE: *SFI's Cowan and Miller campuses were abuzz this summer with immersive education programs. The collage above captures some of the collaborations and instruction at the heart of two summer programs — the four-week Complex Systems Summer School (CSSS) and 10-week Undergraduate Complexity Research (UCR) program. Together, these programs drew 64 participants who represented 24 different countries and included undergraduate, master's, and Ph.D. students, postdoctoral fellows, journalists, and professionals in various industries. (photos: Douglas Merriam)*

RESEARCH NEWS BRIEF

UNEQUAL FOUNDATIONS: TRACING THE ORIGIN OF WEALTH INEQUALITY ACROSS 10,000 YEARS

Economic inequality is one of our primary global challenges and is a key research topic for archaeology — why do some societies become deeply unequal while others remain more balanced? What clues about our economic past are hidden in the ruins of ancient homes?

A recent Special Feature in *PNAS*, edited by SFI External Professors Tim Kohler (Washington State University) and Amy Bogaard (University of Oxford), and facilitated by External Professor Scott Ortman (University of Colorado Boulder), highlights papers by archaeologists, anthropologists, historians, and economists exploring these questions using a global database of over 53,000 residential buildings from about 4,000 archaeological settlements.

Residential building size offers a durable and widely available proxy for household wealth, write the editors in the Special Feature introduction. By analyzing differences in house size, the papers in this issue offer a standardized, cross-cultural, and long-term perspective on economic inequality extending well into periods before writing emerged.

Differences in house sizes over time record when and how wealth gaps emerged, shifted, and sometimes narrowed across 10,000 years of human history. This approach sheds new light on the causes and consequences of inequality, and on how social and political choices shaped the distribution of resources and opportunities in societies around the world. Collectively, the ten studies in this Special Feature offer new insights into the roots and complexity of economic inequality.

"These patterns are deeply embedded in our history," Kohler says. "By studying them, we can better address their implications for the future. If we can understand how inequality emerged and evolved, perhaps we can learn how to mitigate its impact today."

Read the Special Feature, "The Global Dynamics of Inequality over the Long Term" in* PNAS *at https://www.pnas.org/topic/567

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