Winter 2019–20

Parallax

THE NEWSLETTER OF THE SANTA FE INSTITUTE

Domestication (Image: Jody Hewgill)

Working group chases wild ideas on domestication

We humans love cats and dogs. We raise chickens and collect their eggs. We drink milk from cows, eat bread from wheat, and wear sweaters of wool from alpacas and sheep. What would life on Earth be were it not for the domestication of plants and animals?

For more than 10,000 years, domestication has shaped human evolution and the world as we know it. Yet researchers still have a lot to learn about this remarkable phenomenon. "Domestication is not just something that happens to other species; it's also happening to us — it's a relationship," says SFI External Professor Amy Bogaard, professor of Neolithic and Bronze Age Archaeology at the University of Oxford. It's a complex, long-term, multi-generational process in which "we're all affecting each other's evolution."

That marks a dramatic shift in thinking about domestication, which was long mischaracterized as "human mastery of the environment or the wild," she says.

Bogaard is working with University of Oxford evolutionary biologist Greger Larson, director of the Palaeogenomics & Bio-Archaeology Research Network, to bring 16 researchers to SFI March 9–11 to debate the most cutting-edge research and questions about domestication. "The conversation is necessarily cross-disciplinary," Bogaard says, with participants in zooarchaeology, archaeobotany, genetics, anthropology, and more.

But a precise definition of domestication is not on Larson's agenda. "We are instead querying the nature of relationships between human groups and lots of different plants and animals, and then how all of those things get complicated because they all start integrating with each other," says Larson.

As an icebreaker, Larson will ask each researcher to share "the most radical, crazy idea about the origins of domestication." It's intended to be a fun but productive conversation that transcends traditional silos of thought.

Understanding our origins is key to understanding who we are, Larson says. "The entire planet and everything that we're surrounded by — including our electricity and our clothes and our houses and everything that we take for granted about the way in which we interact with the planet — is predicated upon a relationship that is a domestic one between us and a bunch of plants and animals. And we still really don't have the foggiest clue of how this all came about."

Decarbonizing the energy supply

Shifting from carbon-emitting energy sources to renewable ones will be an essential part of addressing climate change, but the path to a renewable power grid is uncharted. A few states have already set specific renewable energy goals; last March, New Mexico passed legislation mandating that, by 2045, the state's public electric utilities will be 100 percent carbon-free. This February 26-28, an SFI working group will explore how New Mexico might best approach the transition to renewable energy sources, and what lessons could be useful for other regions.

The working group will include SFI faculty and other researchers, as well as experts who work in advocacy, government, and New Mexico's public utilities.

"SFI has held lots of workshops on the theory of power grids, but to really work toward decarbonization, we need to dive into the details — hence the mix of local and global expertise," says SFI Professor Cris Moore, who is organizing the workshop with External Professors Jessika Trancik (MIT), Seth Blumsack (Penn State), and Paul Hines (University of Vermont). Moore expects the meeting will result in "strategies specific enough to New Mexico to be useful, but at the same time provide insights that we can export to the rest of the world."

Planning for a low-carbon energy future is inherently uncertain. We don't know how demand, prices, or regulations will shift, and renewable energy sources themselves are variable over different timescales. Planning for daily fluctuations in wind speed or sunlight will require different technological and financial strategies than for rare, severe events that might, say, envelop an entire region in cloud cover for a week.

A primary question in planning a net-zero energy system is how to avoid highly suboptimal lock-in, says Trancik. "Once infrastructure and technology develop, it can be hard to put on the brakes. If we move toward a renewables-heavy system, for example, we'll need ways to address extended shortages even if they pop up only, say, a few times every twenty years," she says. It's important to plan now for future challenges,

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Bill Miller inaugurates namesake campus

Poised with a pair of golden shears, SFI Board Chair Emeritus Bill Miller addressed a crowd gathered at SFI's newly renovated Miller Campus in Tesuque, NM during the annual Applied Complexity Network & Board of Trustees Symposium.

At the surprise ceremonial debut, Miller thought of Ludwig Wittgenstein — the genius philosopher who spent the latter part of his career chasing "snippets" of insight across a range of topics.

"The early Wittgenstein was all about solving problems," Miller said. "He wanted to ground language in logic, so he wrote the *Tractatus*." Following a meeting with critic Frank Ramsey, Wittgenstein "completely changed his way of thinking, and spent the rest of his career on philosophical investigations which were just forays, snippets into this or that."

Why we should bother with snippets of isolated insights is a recurring question for Miller, and for SFI. A legendary investor, Miller is often asked how he chooses his investments, and whether his time at SFI has had any practical applications to his work. In response, he gives examples:

- Citing External Professor Brian Arthur's work on lock-in technologies and path-dependence, Miller says he was inspired to research and buy technology stocks such as Dell, AOL, Nokia, and Apple in 1995 when they were widely perceived as too unpredictable.
- Based on an insight from an early SFI topical meeting on innovation and evolution, Miller says he bought Google shares on their Initial Public Offering (IPO), when each share went for $85. The current share price hovers near $1,500.
- He discussed Geoffrey West's work on scaling laws and company mortality during a recent long-term planning meeting with Jeff Bezos and the Amazon.com leadership. (Miller is one of Amazon's early investors.)
- Finally, Miller credits a 2015 SFI symposium on

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David Krakauer and Bill Miller (Photo: Gabriella Marks)

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BEYOND BORDERS

CANTOR'S INVISIBLE CHEMISTRY

No matter how carefully and ingeniously you rifle and forage through the mathematical archives you will not find a trace of psychoanalysis or a single mention of the periodic table in Georg Cantor's diagonal proof of infinite sets. And this is true despite the universality of Cantor's findings and the fact that the idea of infinity pervades all of science, mathematics, logic, and even mythology.

As it is written in the Upanishads, "there is no joy in the finite, there is joy only in the infinite." For complicated reasons that have nothing to do with the nucleus accumbens or dopamine receptors — the putative anatomical and neurochemical basis of pleasure — we understand perfectly what these Sanskrit inscriptions are getting at without invoking their cognitive infrastructure.

Just like Cantor's proof, the Upanishads are understood within their own system of rules. We do not require for deeper understanding that the insights of logic and mythology be presented through any reductive potpourri of biological mechanisms. These might expand our understanding of cognition but not the correctness of a proof or acumen of a metaphor.

The mysteries of the universe that complexity science seeks to explain are how widespread adaptive regularities emerge at multiple different levels and how each level comes to be best served by its own effective theory — from the theory of molecular interactions through to the theory of ecological stability. And furthermore, the way many of these theories share striking family resemblances by virtue of constraints of energy, time, and information. This is the fundamentally dual nature of complexity theory — recognizing the need for the autonomy of theories at different levels while at the same time exploring the common features of these theories.

Consider two profound representational frameworks — mathematics and natural language — that both use their own specific rules to explore and explain the worlds that they each represent. A paradox presented in natural language or mathematics is explained in terms of mathematics or language. Not in terms of psychology or the covalent bond. At the same time both math and natural language share the properties of syntax and semantics and conform to limitations of length, clarity, and comprehensibility. Thereby each serves the functions required by their contingent domain of application while possessing deep meta-theoretical affinities by virtue of shared structures, processes, and shared users (that is, human beings).

At a recent meeting hosted in Washington by the National Science Foundation and requested by the director of the NSF, France Cordova, and Kraston Blagoev from the division of physics, SFI convened a group of complexity researchers to summarize our current understanding of universality in complex systems.

Spanning pattern-formation, neuroscience, ecology, evolution, and collective computation, researchers reported on amazing regularities that apply across species and across niches and that can be understood by shared principles of scaling, evolution, information theory, and computation. While each area was presented without recourse to reductionism (that is, explanations dominated by interactions among microscopic constituents) common principles of entropy production, robust information encoding, convergent evolution, higher-order interactions, the control of networked components, and the efficient use of energy to store adaptive information, emerged as foundational principles in all complex systems.

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SFI IN THE NEWS

Since its release in September, External Professor **Allison Stanger's** new book, *Whistleblowers: Honesty in America from Washington to Trump*, has been featured in nearly two dozen outlets, including *The New Yorker*, *The Atlantic*, *NPR*'s "Morning Edition," the *Washington Post*, and *The New York Times*.

The *CBC* featured External Professor **Jessika Trancik** in a November 9 story about second-life solutions for aging batteries from electric vehicles.

SFI External Professor **Dan Rockmore** published an essay on November 7 in *The New Yorker* about where new ideas come from, and how to keep the brain moving and "get unstuck."

A November 8 *BBC* article explores Parkinson's Law — the concept that any given task will take up as much time as it is allotted, originally intended to point out inefficiencies in bureaucracies — citing External Professor **Stephan's Thurner's** mathematical models testing Parkinson's Law.

SFI Davis Professor of Complexity **Melanie Mitchell's** new book, *Artificial Intelligence: A Guide for Thinking Humans*, received reviews and mentions in outlets including *The New Yorker*, the *Chicago Tribune*, *The New York Times*, and the *Christian Science Monitor*. Mitchell also appeared on External Professor **Sean Carroll's** podcast, "Mindscape," on October 14.

On October 29, the *Christian Science Monitor* quoted External Professor **Michael Kearns** in an article about surviving the first "deep fake" election. Kearns also spoke with *NPR*'s "Marketplace" on November 1 about his new book, *The Ethical Algorithm: The Science of Socially Aware Algorithm Design*.

On October 16, *HowStuffWorks* published an article on quarks, featuring work by SFI Co-Founder **Murray Gell-Mann** and quoting Past President and Distinguished Shannan Professor **Geoffrey West**.

SFI President **David Krakauer** published an op-ed on October 11 in *Scientific American* on the intellectual value of movement through space.

Arizona Public Media featured research by External Professor **Brian J. Enquist** in an October 11 audio story on how forests will respond to climate change.

Bloomberg profiled External Professor **Doyne Farmer** in an October 3 feature on his work uncovering financial risks that regulators miss.

Why Congress cares about Regional Transmission Organizations (and you should too)

RTOs are charged with helping ensure a reliable electrical grid. (Photo: Matthew Henry)

For something as ubiquitous in modern life as electrical power, few of us know much about the rules that govern power production, fees, or transmission. Most people, including academics and lawmakers, know even less about the Regional Transmission Organizations, or RTOs, that develop those rules. But last September, committees from both the U.S. House and Senate invited SFI External Professor Seth Blumsack, with colleagues from Boise State University and Duke University, to fill them in on what the researchers have learned through a recently funded project called RTOGov (short for RTO Governance).

RTOs were first formed in the late 1990s as part of a federal initiative to restructure the electric utility industry and break up the electrical monopolies that then provided power to the country. RTOs are charged with helping ensure a reliable electrical grid at the lowest possible cost, but the rules for how they achieve these goals are determined not by federal regulators but by a group of regional stakeholders that may include power companies, utilities, and financial players like hedge funds and banks. "Who is actually at the table making these rules, and how much each vote counts, varies by region," says Blumsack. The goal of the RTOGov project, which has been supported by the Alfred P. Sloan Foundation and the Heising Simons Foundation, is to understand how RTOs make rules and how these rule-making processes affect the operation of regional grids.

The rules that RTOs set govern things like fee structures, cybersecurity, and how much energy on the grid can come from which sources — the ratio of renewable energy to fossil fuel-based power, for instance. RTOs can also develop incentives for certain types of power generation. "They basically determine the economic environment for new technologies, and the tools that people operate the power grid have available to keep it going reliably," says Blumsack. The details can look wildly different from one region to the next. Now, House and Senate committees are trying to figure out if things have changed so much since the 1990s that we need to rethink the mission, goals, and oversight of these organizations, he says.

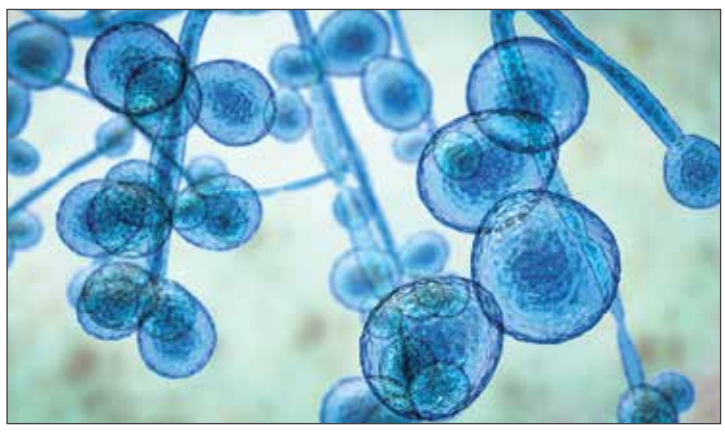
As new technologies are developed, and as states set goals toward decarbonization, RTOs play a critical role. "If you care about electricity costs or reliability or sustainability, these RTOs are incredibly important," says Blumsack. "They're the most important sustainability organizations you've never heard of. A lot of our ability to facilitate technology transition in electricity while keeping it reliable is not just technology, but the environment in which rules and regulations are made."

Working group to study aging in single-celled organisms

What does it mean to grow old? Many fields have offered answers, but none of them provides a universal theory. According to former SFI Postdoc Jacopo Grilli (International Centre for Theoretical Physics), we understand the *when* but not the *how* of aging: when the components of an organism fail, but not the causes of these failures or if the process serves an evolutionary purpose.

This February, a diverse international working group will meet at SFI to find a fresh take on the problem. Grilli and fellow organizers SFI Professor Chris Kempes, External Professor Srividya Iyer-Biswas (Purdue), and Matteo Osella (University of Turin) will focus the discussion on single-celled organisms like bacteria and yeast in hopes of finding generalities in simpler settings. Part of the challenge, Grilli says, has been that aging happens across many scales, from DNA and proteins to organs and entire organisms. By narrowing the inquiry, the group intends to prune the complications and see aging in its essence. A single yeast cell may provide analogies for human beings, and colonies are in some ways like organs. "Looking at things in this way," says Grilli, "allows us to see multiple levels at the same time."

One goal is to identify fruitful questions for a laboratory setting. Grilli notes the project has recruited members "with the experimental expertise to actually test theories in the real world." Sri Iyer-Biswas and Lin Chao (UC San Diego) are two such researchers whose innovative labs can track individual bacteria throughout their life cycles.



Candida auris fungi, emerging multidrug resistant fungus (Image: Kateryna Kon)

"A key challenge in aging studies has been to identify clean experimental systems in which extrinsic (e.g., environmental) and intrinsic (e.g., genetic) factors contributing towards the aging of an organism can be precisely controlled," says Iyer-Biswas. "Consequently, even basic questions such as how 'aging' should be defined remain open."

In her SFI Community Lecture, Iyer-Biswas noted that new methods in cell biology reveal a cellular unit of time. "One can now ask questions we've had a hard time getting a handle on previously," she observed. "The scaling laws for growth and division of cells as they age remain the same, except the cellular unit of time itself gradually slows down."

The implications are far-reaching. This workshop, Grilli hopes, "can unify views on aging, how it's similar and different across the tree of life." As biology itself approaches its 400th year, perhaps the discipline is ripe for more perspective.

(Image: Lanju Fotografie)

Workshop to explore diversity, inequality through "science of science"

In his 2008 Einstein Lecture to the American Mathematical Society, the physicist Freeman Dyson noted, "When I look at the history of mathematics, I see a succession of illogical jumps, improbable coincidences, jokes of nature." As an example, Dyson cited Erwin Schrödinger's discovery that his wave optics equation happens to describe the behavior of atoms. The revelation that nature functions with complex numbers and not real numbers shocked both Schrödinger and the greater scientific community.

The "science of science" is a growing interdisciplinary field with a broad goal of understanding the structure and dynamics of science itself. The discipline evaluates the relationship between scientists and their scholarly products to try to determine the drivers of scientific discovery.

In March, SFI will host a workshop, "A New Synthesis for the Science of Science." The workshop is being organized by SFI External Professor Aaron Clauset (University of Colorado Boulder), SFI Professor and Cowan Chair in Human Social Dynamics Mirta Galesic, and former Omidyar Fellow Daniel B. Larremore (University of Colorado Boulder). The meeting will bring together a diverse collection of researchers to formulate a synthesis of concepts, models, methods, and data to craft a new vision for the science of science.

The workshop will also focus on the individual and structural inequalities within science that slow the pace and limit the diversity of discovery. Specifically, participants will explore the mechanisms that produce epistemic and social inequality. For example, why do a handful of graduate programs produce 50 percent of all tenure-track faculty across different fields? Or why do women produce fewer papers throughout their careers than their male peers?

"Scientific investigations of complex problems benefit from diverse perspectives," says Galesic. "This research can help us to see how some deeper changes in the system can alleviate structural barriers and inequalities."

By using the scientific method to study the scientific ecosystem, the organizers hope to set an agenda for the future growth of the science of science.

"The past 20 years have been really exciting because now we have the data and computational tools to understand the creation of new knowledge," says Clauset. "This workshop aims to articulate the organizing questions that should guide the next five to ten years of work and help us address the underlying causes of pervasive inequalities in science."

Wealth inequality and social network structure

The historic wealth of Istanbul and Singapore owed much to their positions on the Bosporus and the Malacca Strait, respectively. Situated on an essential link in the flow of wealth, the elites of these cities profited from their hold-up power.

Singapore's lavish vertical gardens (Photo: Duy Nguyen on Unsplash)

An ongoing project of the Behavioral Sciences Program at SFI is exploring this basic idea, but applied to wealth differences within societies: Social networks with bottlenecks like the Bosporus or the Malacca Strait may support high levels of wealth disparity. Similarly, the company store stands between the miner and the suppliers of the necessities of life on which his family depends. The elevated prices that the miner pays results from the hold-up power that stems from what network theorists call the 'centrality' of the company store.

An NSF-funded research project is exploring the effects of network structure on wealth inequality. In February over 40 anthropologists, economists, and others will review their research so far and chart new directions.

"The amazing thing about this project," says Eleanor Power, former SFI Omidyar Fellow now at the London School of Economics and co-Primary Investigator on the project, "is that we have the data being collected in almost 50 communities around the world and for two different periods of time, all using the same measurement protocols." The scope of the data will allow systematic comparisons across vast differences in technology, culture, and institutions.

"A key research objective," says SFI External Professor Matthew Jackson, a project leader from Stanford University, "is to determine which types of networks, inequality, and other institutions can exist together — are consistent with each other — and which are not."

SFI Professor Samuel Bowles, another project leader, explains, "based on our theoretical work with former SFI Omidyar Fellow Willemien Kets and SFI External Professor Rajiv Sethi, there are good grounds to think that economies with star-like networks will be more unequal than those with more densely connected networks. But we'll see what we learn from the data."

Jeremy Koster of the University of Cincinnati is among the project organizers: "Coordinating a quantitative project in collaborative cross-cultural research of this magnitude requires a lot of interdisciplinary brainstorming, trust-building, and skill sharing; this is why we are coming back to SFI in February."

History's arc bends toward quantification

This January, SFI researchers will take a quantitative look at an age-old question: to what extent is human history shaped by impersonal trends, big ideas, and great leaders?

"Historians have qualitatively debated the relative roles of these phenomena, and it's clear all three have had some effect throughout history," says SFI Professor David Wolpert, who is co-organizing the working group with External Professor Manfred Laubichler (Arizona State University), Applied Complexity Fellow Michael Price, and Program Postdoctoral Fellow Hajime Shimao.

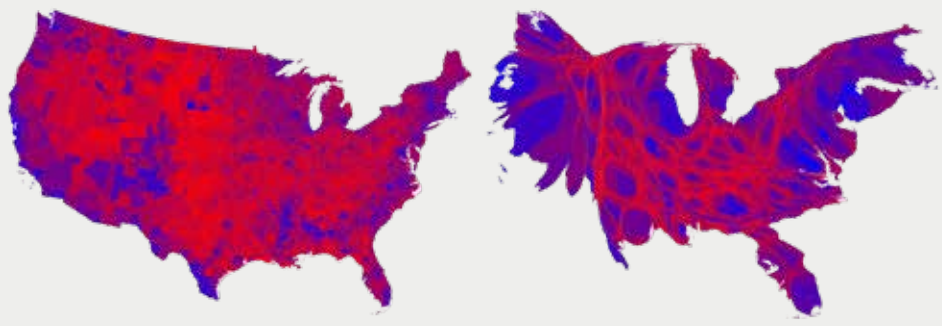
"We're now at a point in time where we can begin to explore, quantitatively, which of these has been most important, and when," Laubichler says.

Take the fall of Rome, for example — a complex collision of new ideas, such as Christianity; the cult of personality around Roman emperors; and impersonal plagues and population movements. Scholars have long argued about which of these many factors might have broken the empire's back. Now, thanks to a bloom of new archaeological datasets, it may be possible to actually quantify how much each of these factors impacted the Mediterranean and Europe.

As an example of the type of research the group is pursuing, Price cites a recent paper on the Justinian Plague, published in *PNAS*. By amassing and analyzing archaeological evidence drawn from papyri, coins, inscriptions, and pollen, the paper's authors were able to test popular claims that the pandemic, estimated to have spread between 540 and 750 CE, played a key role in the decline of the Roman Empire and the subsequent transition from antiquity to the middle ages. (Spoiler alert: it did not.)

The working group builds on previous SFI research into "Computational History," "Big History," and "Cliodynamics," which seek to uncover mathematical patterns in human history to better understand its underlying dynamics. To that end, the group will be honing analytical tools from complexity science, such as time-series analysis, to crack open the "torrent" of historical and archaeological data that has been growing over the past two decades.

RESEARCH NEWS BRIEFS



A regular map of the United States showing results of the 2016 presidential election by county, with red, blue, and purple to indicate voting percentages (right). A cartogram (left) illustrates the same data, but skewed to represent population. (Images: SFI External Professor Mark Newman)

RESEARCH FOR AN ELECTION YEAR

Media in the U.S. have already been covering the lead-up to the 2020 U.S. presidential election for months, and in the years since the 2016 election, researchers at SFI have been taking a complex systems approach to understanding the political landscapes in the U.S. and around the world. As we enter this election season in earnest, here are some of the highlights of our election-related science, from new ways to illustrate political maps to different polling questions for better predictions.

WHAT MATTERS IN AN ELECTION?

In 2016, SFI External Professor Mark Newman (University of Michigan) developed a variety of election cartograms that play with scale, representing counties and states proportionally based on their populations or representation in the electoral college. These graphical representations offer a fresh perspective on the political landscape in the U.S. by combating the "apparent paradox" of the traditional, geographically proportional red-and-blue map. This paradox, Newman notes on his website, "fails to allow for the fact that the population of the red states is on average significantly lower than that of the blue ones. The blue may be small in area, but they represent a large number of voters, which is what matters in an election."

IT'S *WHO* YOU KNOW, NOT *WHAT* YOU KNOW

We usually rely on polling to predict election outcomes, but those polls are not always reliable; in the 2016 U.S. presidential election, Hillary Clinton lost in five states where polls had anticipated her victory. In a February 2018 paper published in *Nature Human Behaviour*, SFI Professor Mirta Galesic and co-authors examined an alternative approach. Whereas most election polls ask people about their own voting habits, Galesic and her colleagues found that questions about the views of a voter's social circle actually provide more insight, improving the accuracy of voting predictions. The researchers studied the usefulness of social-circle questions in both the 2016 U.S. presidential election and the 2017 French presidential election by means of national pre-election surveys and aggregate polls. The results indicate the efficacy of social-circle questions in tapping into 'local' wisdom rather than asking potential voters to make assumptions about the behavior of the general population.

REALISTIC IF NOT (YET) REAL

In the May/June 2019 *Comptes Rendus Physique*, SFI Professor Sidney Redner offered a mini-review of the voter model that has played a central role in both probability theory and statistical physics. The classic voter model, which randomly selects a voter who then adopts the state (voting habits) of a neighbor, lacks nuance, resulting in consensus that is not always achieved in reality. In his review, Redner presented a variety of extensions to this model that endeavor to incorporate socially motivated aspects of decision making. A lack of corresponding empirical data means we should avoid mistaking these extensions for social reality, but they provide useful descriptions of how opinions can change over time in large-scale populations.

FORENSIC ANALYSIS FOR VOTER FRAUD

The U.S. isn't the only country concerned with voter fraud. The results of Turkey's 2017 constitutional referendum indicated majority support of the country's shift to autocracy, but allegations of electoral irregularities and misconduct suggest otherwise. In a 2018 *PLOS One* paper, SFI External Professor Stefan Thurner (Complexity Hub Vienna) and his collaborators applied statistical forensics tests to identify and verify cases of malfeasance. They utilized

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72 hours of sci-fi: Transmissions from an alien civilization

In November of 2019, 14 SFI postdocs withdrew to an isolated research location to accomplish, in just 72 hours, a monumental task — decoding the first complex communication from an alien civilization.*

The SFI postdoctoral fellows in front of their signal receiving structure. (Photo: Santa Fe Institute)

For the benefit of humanity, the aliens managed to divert their spacecraft for enough time to transmit a scientific treatise on a fundamental difference between their complex biology and ours. They were responding to images on the Golden Record, which launched aboard the Voyager spacecraft in 1977, engraved with a cosmic introduction to Earth and its inhabitants. Among the record's 115 encoded images were multiple depictions of the two-parent system of reproductive biology. "The aliens were totally shocked by these images, because in their world children are conceived and raised by three parents instead of two," says Albert Kao, an Omidyar Fellow and Baird Scholar. "For scientists who study complex, living systems, it brings up all kinds of interesting questions about why three-parent systems would arise and what that might imply for the evolution of everything from molecular mechanisms to social institutions."

With combined expertise in biology, evolution, information theory, mathematics, physics, philosophy, archaeology, cognitive science, and economics, the postdocs were uniquely qualified to receive and interpret the wide-ranging alien treatise. In three days and with little sleep, they documented biological consequences of tri-parental reproduction at multiple levels — the braid-like combining of the aliens' chromosomes, the size differentiation between their gametes, the coordination of "mating events" among three sexes, and the cultural implications of their family structures.

According to the postdocs, the aliens' three-parent system confers a distinct evolutionary advantage over a two-parent one. Just as sexual reproduction protects organisms from the harmful mutations that proliferate in asexual species, like dandelions, the three-parent reproductive system adds another layer of protection and genetic diversity, especially on planets bombarded with high radiation, which can cause a high mutation rate.

Exactly why the aliens' three-parent system came to dominate, as opposed to a four-, five-, or *n*-parent system, might be explained by the coordination costs and social ramifications of searching for multiple mates at once. In their treatise, the authors describe the exponential difficulty of finding a "soul triplet"— a perfect romantic combination in a sea of possibilities.

Other social consequences of the three-parent system include a heightened risk of disease transmission and a societal trend towards a uniform culture. According to Omidyar Fellow David Kinney, such a uniform culture is needed to avoid the cognitive overload caused by trying to juggle the cultures and languages of three parents, nine grandparents, and potentially dozens of partial siblings.

"There are so many social angles to explore in this system," says sociologist Tamara van der Does, a Program Postdoctoral Fellow. "The number of biological sexes would have ramifications across all aspects of an alien culture, from gender inequality to institutions like marriage and religion. After 72 hours, we were just starting to scratch the surface."

Omidyar Fellow Tyler Marghetis says imagining a three-parent system "is actually a really great way to gain insight into the origins and implications of our more familiar two-parent system . . . in the same way that experiencing other cultures can help travelers better understand themselves."

"There are a lot of interesting questions that can be pursued in this model," says archaeologist Stefani Crabtree, an ASU–SFI Center Postdoctoral Fellow. "One of the great things about being a postdoc at SFI is that you have expertise in one area, but you also get exposure to other fields that connect to it."

After 72 hours of intense transcription, the postdocs steeled themselves to record the final transmission in the treatise — the core innovations of alien culture, including "hyperdrive technology, the unified theory of physics, and the meaning of life." Unfortunately, this final portion of the transmission did not arrive intact.

The full treatise on three-parent reproduction, replete with figures and references to terrestrial scientific literature, will be published in the summer of 2020 in conjunction with the Inter-Planetary Festival.

**The alien transmission is a fictional premise. Any resemblance to actual species, civilizations, or planets is purely coincidental.*

'To make rigor accessible to everyone'
SFI welcomes Director for Education

In the few short months since Carrie Cowan arrived at SFI, she's been immersed in the culture and in uncovering new ways to advance the Institute's educational mission. But the moments that most stand out to SFI's new Director for Education are all about the people.

"Some of the most remarkable experiences have been lunchtimes and teatimes, when you just sit down with random people," Cowan explains. "You end up having these amazing conversations about science and about life — always with a lot of intellectual curiosity."

Cowan joined SFI in September from Jackson Laboratory, a biomedical research institution in Maine, where she oversaw Ph.D. and postdoctoral training. She led similar efforts at New York's Cold Spring Harbor Laboratory following a research career at the Research Institute of Molecular Pathology in Vienna, Austria. Her journey to SFI — and to complexity science —started early on.

"I'm a scientist by training and was very interested in how cells create spatial patterns and make decisions based on that information," she says. "My work wasn't necessarily complex systems, but it was adjacent, and I always had SFI in my mind."

Once Cowan started her own research group and was training postdocs, she gravitated toward education. She was particularly interested in the process of preparing our next generation of scientists — not just with intellectual skills, but in the practice of science.

"My interest in patterning and decision-making across systems connects me to SFI research," Cowan explains. "But I also have a holistic view

Director for Education Carrie Cowan (Photo: Scott Wagner for the Santa Fe Institute)

of training. To look at things from multiple perspectives, not just the one discipline I took a bunch of courses in, gives me a much more liberal view of the world, and that's essential in how we structure education."

Cowan's perspective on education aligns with SFI's mission, especially when it comes to expanding the reach of complexity science.

"We want SFI's rigorous approach to be available to everybody," she says, "so Complexity Explorer, our online platform, includes great courses on how the math works and what it means. That's the goal: to make the rigor accessible to everyone."

Unraveling in time

The average skin cell lives for 28 days. A white blood cell, four months. Yet a human being might live 90 years or more, unaware of the millions of lifetimes unfolding at their own paces inside.

"We tend to think of time in terms of a constant rate, but in a complex system there are multiple clocks that are all ticking at different rates," says David Krakauer, SFI President and William H. Miller Professor of Complex Systems.

It's this cacophony of clocks that has produced one of the most persistent of urban legends: that all the cells in our bodies get "replaced" every seven years. That's not true — not even close! — but it points the way towards profound questions about the way time operates in the body and beyond.

It's not just a matter of scale. That same human body also observes a circadian time, a rhythm dictating sleep and waking. Invading pathogens might wreak havoc within, following their own timescales of life, reproduction, and death. The brain and body age and break down. In the world outside, ecosystems grow and change on myriad simultaneous schedules. So do cities, economies, philosophies, species. Meanwhile, human bodies participate in all the trappings of economic and political time, from 9-to-5 days to bull markets to the rise and fall of entire systems of government, all the while perceiving psychological time: romances that are over in a flash, commutes that seem to last forever.

"In each of the application areas, we want to know how time organizes phenomena ," but "the deeper set of issues has to do with how things unravel in time . . . and that's the common theme in all of these.

Given the seemingly endless layers of time in complex systems, it makes sense that, until now, working groups in SFI's research theme on Adaptation, Aging, and the Arrow of Time have studied them separately. For instance, one group has focused on the nature of sleep, while others have explored ecological evolution, infectious diseases, or cognitive regime shift.

However, an upcoming meeting, held April 2–4, 2020, will mark an exciting development.

"We have all these topical areas that have been meeting in isolation, and it's time to bring them together," says Amy P. Chen, Program Manager for Adaptation, Aging, and the Arrow of Time.

The upcoming gathering combines the program's annual General Meeting with its Core Theory meeting, as well as inviting contributions from the advisory board. The aim: to begin working towards a unified theoretical approach to time.

To that end, rather than being presentation-focused, "there will be a lot of time for group discussions, so [participants] have a chance to hear from each other," says Chen. "There will be a lot of time to ask questions."

"The big picture is: what is time?" says Krakauer. "In each of the application areas, we want to know how time organizes phenomena," but "the deeper set of issues has to do with how things unravel in time . . . and that's the common theme in all of these. The time to make something, and the time to break something."

Also integral to the meeting will be new participants, including Simon Grondin (Université Laval, Québec), who can offer insight from areas not currently in the Complex Time portfolio, such as psychology and philosophy.

These are subjects well-equipped to tackle what may be complex time's most mind-bending hurdle: the fact that, as Krakauer notes, "we build the clock." Does absolute time exist, and if so, how could we theorize it?

Only time will tell.


Elizabeth Bradley


G. Matthew Fricke


Mirta Galesic


Joshua Garland


Alfred Mathewson


Cristopher Moore


Melanie Moses


Kathy Powers


Sonia M. Gipson Rankin


Gabriel R. Sanchez

NM experts fight for transparency and fairness in housing algorithms

Leading scientists and legal scholars are weighing in on a national debate about fair housing laws. On October 18, a group of ten computer scientists, social scientists, and legal scholars from the Santa Fe Institute and The University of New Mexico submitted a formal response to the U.S. Department of Housing and Urban Development's (HUD) proposal to dramatically revise the Fair Housing Act.

Key amendments in HUD's new legislation would absolve landlords and lenders from any legal responsibility for discrimination that results from a third-party computer algorithm. Such algorithms are already widespread in our society and are used to automate decisions about who gets a credit card, a lease, or a mortgage. As the proposal is written, landlords and lenders would be protected from charges of "disparate impact" (unintentional discrimination that nonetheless leads to wide disparities) so long as their algorithms don't overtly factor in protected characteristics like race, gender, religion, or disability status, or rely on proxy variables for those characteristics.

According to the experts, the HUD amendments related to algorithms are based on a fundamental "failure to recognize how modern algorithms can result in disparate impact . . . and how subtle the process for auditing algorithms for bias can be." Modern machine-learning algorithms are poorly understood, and often draw highly complex correlations that even their designers may not be aware of. Any combination of factors, from location data to purchase history to musical preference, could be correlated as a proxy for race or another protected characteristic, with devastating consequences for protected groups.

These algorithms are often opaque, but without transparency there is no way to confirm that they are fair. In their letter, the SFI and UNM experts demand transparency, recommending that designers of decision-making algorithms allow independent auditors a minimal level of access where they could test the algorithms for bias by feeding them various inputs and observing how they respond. The authors also demand transparency for individual applicants, allowing them to view their own data and "contest, update, or refute that data if it is inaccurate."

The letter, lays out four arguments against the proposed legislation:

1. To ensure that an algorithm does not have disparate impact, it is not enough to show that individual input factors are not "substitutes or close proxies" for protected characteristics.

2. It is impossible to audit an algorithm for bias without an adequate level of transparency or access to the algorithm.

3. Allowing defendants to deflect responsibility to proprietary third-party algorithms effectively destroys disparate-impact liability.

4. The proposed regulation fails to take into account the cumulative impact of multiple users of algorithms that result in disparate impact on protected classes where no individual user has liability under the proposed regulation.

Their full response is posted on the Federal Register, along with over 3,500 other public comments.

The co-signatories are members of The Interdisciplinary Working Group for Algorithmic Justice and are available to provide thoughts and expertise to policymakers around the use of algorithms in society:

For more information, visit: santafe.edu/research/projects/algorithmic-justice."

DECARBONIZING THE ENERGY SUPPLY *(cont. from page 1)*

and that includes keeping available several paths to deep decarbonization that also ensure reliable energy supply.

While many people are already thinking about specific technologies and solutions to production, storage, and transmission, Blumsack says this working group will be more focused on the transition process, using New Mexico as a test case. "We want to think through the transition process for New Mexico — where the state is going to have to make critical decisions and what those critical points might be — and then offer those lessons to apply in other states."

BILL MILLER INAUGURATES NAMESAKE CAMPUS *(cont. from page 1)*

money and currency, which he co-organized with SFI President David Krakauer, for prompting him to buy Bitcoin when it was trading for $200. By December of 2018, it had hit a high of $20,000. Its value currently hovers between $7,000 and $8,000.

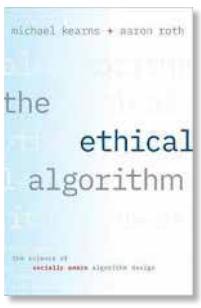
The example of Bitcoin was especially timely, because in 2018 Miller donated $5 million from this SFI-inspired investment to fund the Institute's expansion to the Miller Campus. The estate itself was donated in 2012 by Eugene and Claire Thaw, but needed repairs and renovation before it could become a workspace. Jokingly, Miller refers to it as "the campus Bitcoin built."

"To find somebody who actually shares this kind of vision of how you can live in the world, and supports a community that's devoted to ideas is completely special," Krakauer remarked, praising Miller for valuing risk and exploration, which are central to the "sensibility and culture" of SFI.

The Thaw home, originally designed by renowned architect Betty Boyce Stewart, now boasts streamlined, modern meeting spaces set amidst historic Santa Fe fireplaces and double-thick adobe walls. The new architecture, by Thomas Easterson Bond, is adorned with prints and sculptures by artist Greg Stimac — a special exhibit that celebrates exploration and the American Road.


Researchers, Applied Complexity Network members, and friends of SFI celebrate the dedication of the newly renovated Miller Campus. (Photo: Gabriella Marks)

New books by SFI authors



The Ethical Algorithm (Oxford University Press, 2019) by SFI External Professor Michael Kearns and a colleague at the University of Pennsylvania, Aaron Roth, offers a set of principled solutions based on the emerging science of socially aware algorithm design. The algorithms that dominate much of modern life, from advertising and consumer lending to college admissions and hiring, have also routinely violated basic rights of individual citizens. Most fixes thus far have focused on legal and regulatory solutions, but Kearns and Roth propose fixing technology from the inside with algorithms embedded with precise definitions of fairness, accuracy, transparency, and ethics.

Artificial Intelligence: A Guide for Thinking Humans (Macmillan Publishers, 2019) by SFI Science Board co-chair and Davis Professor of Complexity Melanie Mitchell lays bare the inner workings of the potent tools of AI, exposing their realistic limits and patiently detailing our deployment errors. It presents a plain-speak, human-readable primer on the new technologies that have transformed human culture and society, and uses that foundation to caution the reader against placing more trust in automated systems than they deserve. It is going to be a while before machines can think, and until then we need more people who can think for our machines, and for ourselves.

Asking questions that matter

If you could answer any question you put your mind to, what would you ask?

For Ramanan Laxminarayan this is not a hypothetical, three-wishes kind of question— it's a real dilemma that early career researchers need to confront head-on. March 17-20, during the seventh Postdocs in Complexity conference, he'll be coming to Santa Fe to hash out some answers with the Santa Fe Institute and James S. McDonnell Foundation postdoctoral fellows in a presentation titled: "Asking questions that matter — the choice of where to dig."

"Generally I find there are a lot of bright people out there who can answer any question they want to," Laxminarayan says, commenting on his eight years of experience on the fellowship committee for the James S. McDonnell Foundation. After interviewing scores of talented researchers for the competitive early-career fellowship, he's noticed that raw talent and skill are rarely the limiting factors for applicants. Oftentimes, he says, "they're pursuing a topic where it's not obvious why they're pursuing it."

> Generally I find there are a lot of bright people out there who can answer any question they want to.
>
> RAMANAN LAXMINARAYAN

The founder and director of the Center for Disease Dynamics and Economic Policy in Washington, D.C., Laxminarayan has dedicated his own career to understanding how to counter the global onslaught of antibiotic-resistant bacteria. Though he himself chose to research antibiotic resistance for its potential to save tens of millions of lives, he says good questions don't always have to be utilitarian in nature. Theoretical work, such as Einstein's theories of special and general relativity, unveil secrets of the universe even though they have very little immediate application to peoples' everyday lives.

Whether fellows seek universal principles, real-world impact, or both, Laxminarayan advises them "not to pursue research based on a skill-set or a set of methods," which is often emphasized in graduate education programs. Rather, like SFI and the James S. McDonnell Foundation, he advocates for problem-driven approaches that bring together scientists with different disciplinary backgrounds and skillsets.

As an added bonus, he says once a researcher has found their question, they'll have a much easier time communicating their research to outsiders.

For more information on the seventh SFI-JSMF Postdocs in Complexity Conference, and an agenda, visit https://www.santafe.edu/events/jsmf-sfi-postdocs-complexity-conference-vii.

BEYOND BORDERS *(cont. from page 2)*

There was a time not too many years ago when the idea of general theories of complexity seemed absurd. Early efforts that tended to over-generalize from toy models without strong empirical support engendered skepticism in both the scientific community at large as well as among complexity scientists. The recent turn to strong empiricism has led to discoveries of startling regularity not dissimilar to those discoveries in the physical sciences made over the last few centuries.

This is a very exciting time in complexity science that promises not only to discover emergent laws of nature, but to explain why a diversity of approaches to understanding is required, why a grand unified theory is wrong-headed, and possibly to discover principled means of establishing connections across the full landscape of complexity theories.

— David Krakauer
President, Santa Fe Institute

Parallax

Winter 2019–20

THE NEWSLETTER OF THE SANTA FE INSTITUTE

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RESEARCH NEWS BRIEFS

(cont. from page 5)

election data made available on the election commission's website, removing potential outliers and examining election fingerprints. The researchers found "systematic and highly significant statistical support for the presence of both ballot stuffing and voter rigging." These statistical irregularities persisted in the 2018 presidential and parliamentary elections, indicating systematic biases that need to be combated.

WHY DO SO MANY ELECTIONS VERGE ON STALEMATE?

History offers up numerous examples of near 50-50 election results. In the past decade alone, we've witnessed the 2014 Swiss referendum on mass immigration, the 2016 U.S. presidential election, and the British Brexit vote (also in 2016). All three were characterized by controversial issues and hostile attacks on both sides, and all three ended in a near stalemate, with a narrow margin of defeat or victory for the losing and winning parties.

In a 2019 paper in *Physical Review E*, SFI collaborator Stefan Bornholdt (Institute Rudjer Boskovic) and his colleagues present a voter model that explains what drives public opinion toward stalemate. In a word, it is repulsion. As voters are either convinced or repelled by statements, they can change sides or switch to an undecided state if they come to doubt their former opinion. In a contentious debate, when a voter is repelled by at least one out of four statements, a phase transition occurs where neither party can win in the long run and no clear winner emerges. To shift these dynamics from stalemate to majority, the study offers several recommendations for moving away from hostile statements and toward rational discourse. Their most radical proposal? "To declare results as invalid where the difference between yes and no is less than ten percent."

UPCOMING COMMUNITY EVENTS

SFI COMMUNITY LECTURE SERIES: SPRING 2020 LINEUP

The Santa Fe Institute Community Lectures bring leading thinkers to Santa Fe to explore the most alluring questions in science, and to address the complex issues that face our species and our planet.

Our 2020 series kicks off February 25 and runs through November at The Lensic Performing Arts Center. Lectures are open to the public; seating is limited. To reserve your free tickets, visit santafe.edu/community

Tuesday, February 25

RAJIV SETHI

"Stereotypes, Crime, and the Pursuit of Justice"
7:30 p.m., The Lensic Performing Arts Center

Tuesday, March 24

SARA WALKER

"The Information Origins of Life"
7:30 p.m., The Lensic Performing Arts Center

Tuesday, April 28

BARBARA GROSZ

"From Ethical Challenges of Intelligent Systems to Embedding Ethics in Computer Science"
7:30 p.m., The Lensic Performing Arts Center