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Parallax

THE NEWSLETTER OF THE SANTA FE INSTITUTE

Reconciling two views of information

Meaning of Information working group

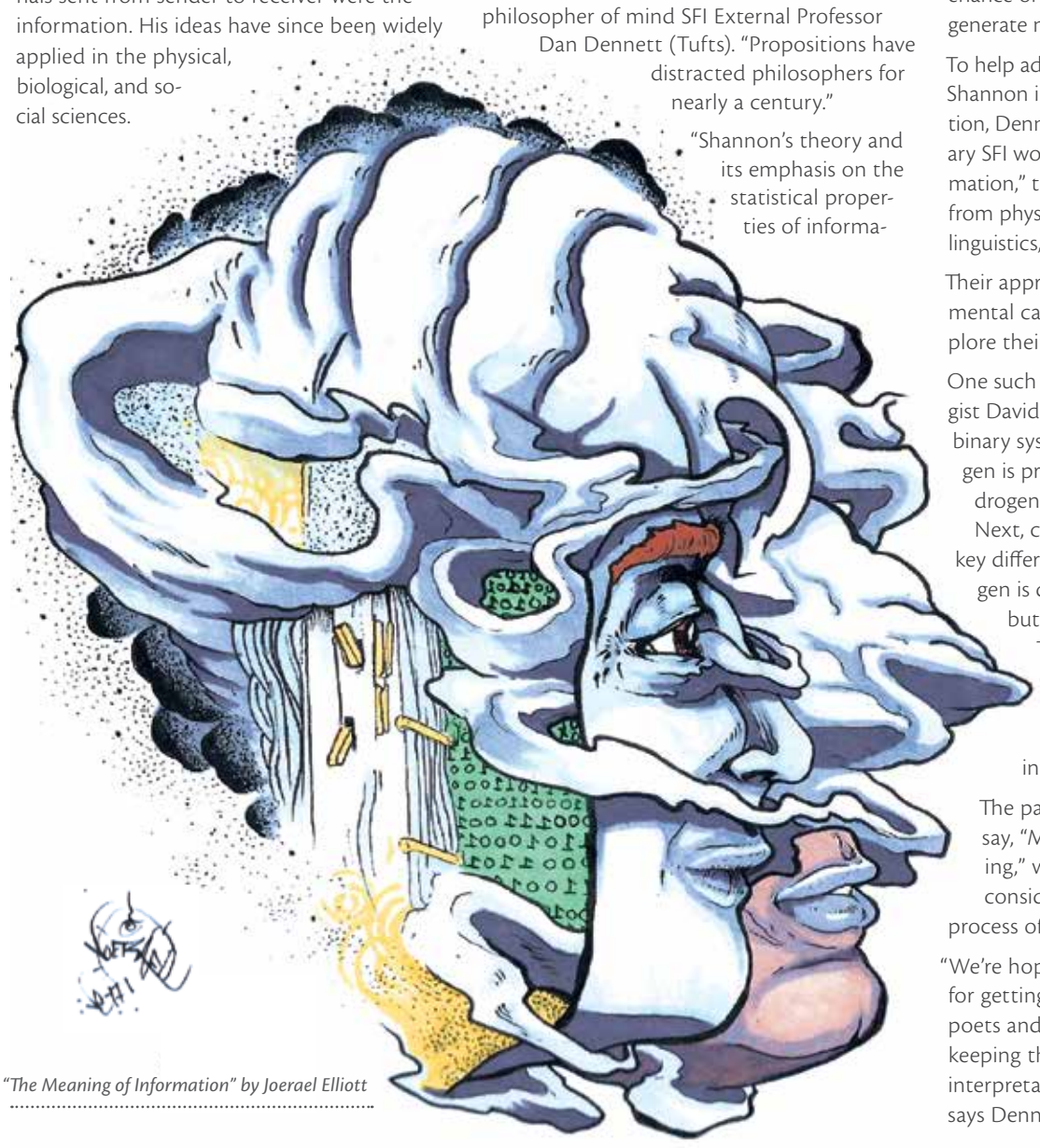
IN 1948 CLAUDE SHANNON, motivated by the engineering challenge of encoding, transmitting, and decoding electronic signals, took the radical step of defining "information" in a way that completely disregarded whatever meaning a transmitted signal might contain.

For Shannon, the statistical properties of signals sent from sender to receiver were the information. His ideas have since been widely applied in the physical, biological, and social sciences.

Meanwhile, over in linguistics and philosophy, scholars continued to wrestle with definitions of information that were *all about* meaning and its interpretation — and focused almost exclusively on human minds and language.

"They've been thinking primarily in terms of language, and of the semantics of true sentences — what they call propositions," says philosopher of mind SFI External Professor Dan Dennett (Tufts). "Propositions have distracted philosophers for nearly a century."

"Shannon's theory and its emphasis on the statistical properties of information have been useful in many scientific and engineering contexts," says SFI External Professor Chris Wood. "But in other contexts, and not just those involving humans, information without meaning seems limiting and unproductive."



"The Meaning of Information" by Joerael Elliott

Is extracting meaning from the world the provenance of human minds? Could a machine generate meaning from its inputs?

To help address the 70-year divide between Shannon information and semantic information, Dennett and Wood are organizing a January SFI working group, "The Meaning of Information," that brings together perspectives from physics, engineering, evolutionary biology, linguistics, philosophy, and neuroscience.

Their approach is to identify the most fundamental cases of semantic meaning and explore their properties and consequences.

One such example, offered by Harvard biologist David Haig in a recent essay, is a simple binary system that strikes a spark. If only oxygen is present, nothing happens, but if hydrogen is present, an explosion occurs. Next, consider the same system but with a key difference: a hydrogen sensor. If no hydrogen is detected, the system strikes a spark, but if hydrogen is detected, it does not. The system with the sensor acts differently based on its environment. Can the system be said to *interpret* the environment? If so, does that interpretation contain *meaning*?

The participants will start with Haig's essay, "Making Sense: Information as Meaning," which proposes that meaning "be considered the output of the interpretive process of which information is the input."

"We're hoping Haig's ideas may be the basis for getting us all the way from molecules to poets and scientists and philosophers while keeping the same definitions of information, interpretation, and meaning throughout," says Dennett.

McKinnons give $3M to expand science at SFI

In one of the largest gifts in the nonprofit's history, Ian and Sonnet McKinnon have donated $3 million to expand fundamental research at the Santa Fe Institute.

The gift, to be deposited in a single installment, will support core SFI science activities, in particular the highly diverse working groups and workshops that are the hallmark of SFI's collaborative approach to the challenges of complexity — looking for emergent patterns across physical, biological, technological, and social systems.

Following an extended dialogue with SFI President David Krakauer about the Institute's scientific impact, the McKinnons announced their gift to SFI science.

"I was delighted by their decision to support core collaborative activities and the generosity of their gift," Krakauer says. "Ian and Sonnet are scrupulous philanthropists who want to make every dollar count. Their willingness to support creative, independent research affirms the societal benefit of investigating fundamental questions about the nature of the complex world."

While SFI researchers are generally motivated by curiosity rather than immediate applications, techniques pioneered at SFI have facilitated advances in drug discovery, ecological conservation, epidemiology, urban planning, and new forms of artificial intelligence.

"The academic freedom and collaborative culture of the Santa Fe Institute draws hundreds of world-class researchers to SFI every year," says Jennifer Dunne, SFI's Vice President for Science. "That kind of convening power wouldn't be possible without support from individuals like the McKinnons." Dunne also notes that for every dollar spent, the Institute leverages more than four additional dollars from federal grants, foundations, and strategic partners.

SFI hosts more than 30 scientific meetings annually and welcomes over 800 visiting scien-

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Opening a centuries-old window on innovation

Patents are one of the best sources of data on technology development — an open-ended, historical and adaptive system that shows us how and why inventions have come to be. But is the U.S. patent system broken?

That question is being raised more frequently these days, as inventors and companies operate in an increasingly competitive ecosystem. For Jose Lobo and Deborah Strumsky, both Fellows of the ASU-SFI Center for Biosocial Complex Systems, it's a question that deserves careful consideration.

Bringing together experts from academia, industry and the legal profession, Lobo and Strumsky are hosting an Applied Complexity Network (ACtioN) working group at SFI March 12-14 to explore the nature of the patent system. And with a complex system that has evolved over the course of 224 years — from hundreds of technologies to hundreds of thousands — there's much territory to explore.

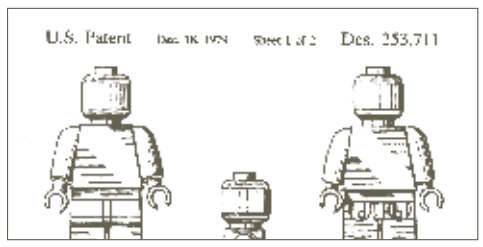
"Part of what makes SFI's approach unique, and what's makes this working group unique, is that SFI researchers want to go beyond talking about analyzing the streams of output from the patent office," Strumsky explains. "This working group calls for a much deeper look into production of information and how it affects our understanding of our world."

The patent system's detailed and precise descriptions of inventions, including data on the inventor, where they worked and when they were working, offers researchers a way to understand technological change in terms of selection, obsolescence, adaptation, and diffusion processes. But the system is also human-powered, and humans are flawed. Can AI help?

Some countries are already using AI to help patent examiners. The strategy seems to be working. AI has been able to replace redundant searches, freeing patent examiners to work with clients and be more responsive to their needs. Examiners can get overwhelmed, but AI never gets tired.

"We need to understand the nature of the patenting system as an information processing and generating system before we can assess how AI can make the patenting system better," Lobo says. "More generally, before a diagnosis of 'the system is broken' is meaningfully made, and a solution proposed, we need to understand the fundamental nature of the system."

To understand that fundamental nature, Strumsky says researchers need to study the patent system as an evolving system that generates enormous amounts new information on a daily basis. "We need to understand how the type of information generated enables and constrains our ability to study technology and understand how we interact with it."



Detail from a patent for a toy that might look familiar

BEYOND BORDERS

MOUNTAINS, MONASTERIES, AND THE METROPOLIS

"Because it's there." —George Mallory

"Monasteries, those scattered danger points, become the chief objectives of nocturnal flight." —Patrick Leigh Fermor, A Time to Keep Silence

"Even in Kyoto, longing for Kyoto." —Basho

Over the course of a creative life there are times when one craves solitude. Albert Camus suggested that "In order to understand the world, one has to turn away from it on occasion." This understanding is followed by the impulse to assemble discoveries within a critical community. For Darwin, this was provided by the Royal Navy sloop, the Beagle, about which he reminisced that "I have always felt that I owe to the voyage the first real training or education of my mind," a sentiment shared with Herman Melville, who wrote of the Pequod: "A whale-ship was my Yale College and my Harvard." And having survived the challenges and improvements of isolated and steadfast community, the now perfected idea is ready to confront the world of the metropolis, Charles Baudelaire's "Ant swarming City, City full of dreams."

The development of an idea is a transit from the deliberative solitude of the Mountain, into the collaborative fraternity of the Monastery, to be finally delivered to the diverse appetites of the Metropolis. Each place corresponds to the needs of a creative stage: contemplation, conversation, and commerce.

The Santa Fe Institute is metaphorically a Monastery in the Mountains — living at the edge of wilderness and society. By contrast, the Salk Institute and the Flat Iron Institute are Monasteries in Metropolises — supporting populations of researchers above the clamors of San Diego and New York City. Very rarely a Mountain is discovered within the Metropolis — such is the John Soane house in Lincoln Inn Fields — one scholar's Mount Kailash in central London.

The Santa Fe Institute is a Monastery dedicated to science, a community with a shared belief in the value of the rigorous pursuit of frighteningly difficult problems. The name of its present home is the Cowan Campus and after thirty years this community is set to expand. Responding to the growing success of complexity science and its evident value to the world, a second scientific Monastery, the Miller Campus, is now in development in Tesuque. Starting with a generous gift of land and property from Gene and Clare Thaw, and now undergoing upgrade, enhancement, and repurposing with a new gift from William H. Miller, SFI will be supported by two campuses: one focused on basic complexity research (Cowan Campus) and the other on its many applications and successful delivery to the Metropolis (Miller Campus). After all, as Edison once observed, "the value of an idea lies in the using of it."

— David Krakauer
President, Santa Fe Institute

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SFI IN THE NEWS

Vox EU published an editorial by SFI Professor **Sam Bowles**, External Professor **Rajiv Sethi** (Columbia University), and **Alan Kirman** (Institute for New Economic Thinking) on Dec. 8. The authors argue that economist Friedrich Hayek's influential market algorithm does not support free-market policies.

SFI's **Cormac McCarthy** returned to "The Kekulé Problem" Nov. 30 in response to readers' questions about his nonfiction essay on language and the unconscious. Both the essay and the response were published in *Nautilus* magazine.

NPR, *Science*, and *The Economist* featured an archaeological study that charts wealth inequality across millennia. The November *Nature* study by External Professor **Tim Kohler** (Washington State University), External Professor **Amy Bogaard** (University of Oxford) and coauthors was inspired by an ongoing series of SFI workshops and working groups on the dynamics of wealth inequality, organized by Professor **Sam Bowles**.

ACtioN alum **Jim Hackett**, now CEO at Ford Motor Company, was featured in a Nov. 9 *New York Times Magazine* article titled "**Can Ford turn itself into a tech company**?" The article includes a description of how Hackett's time at SFI has shaped his thinking.

On Nov. 3, *The Wall Street Journal* asked if fund manager **Bill Miller**, Chairman Emeritus of SFI's Board of Trustees, could create a financial seismograph. Miller is pursuing a quantitative model to predict market crashes inspired by SFI External Professor **John Rundle**'s (UC Davis) approach to forecasting earthquakes.

In a newscast that aired Oct. 24, *KRQE* interviewed SFI Professor **Mirta Galesic** about her online survey project "**SciFriends**" which aims to understand how friends influence each others' thinking.

Newsweek, on Oct. 6, cited SFI External Professor **W. Brian Arthur** in an article about automation and rising income inequality. Arthur's recent essay on technology and the economy was published in the October issue of *McKinsey Quarterly.*

"**Hey Elon Musk, what about toilet paper on Mars?**" A Sept. 28 *CNET* article asked. The article raised questions about interplanetary civilization inspired by SFI's inaugural **InterPlanetary Project Panel Discussion** in Santa Fe.

Can lookahead optimization help us make better decisions?

When NASA scientists equip the Orion spacecraft with medical supplies for its manned mission to Mars, they will choose what to send in light of their best predictions of what the environment will be like there. Yet some of the most difficult scenarios for scientists to predict are those in which agents enter into unknown territories. Can scientists develop methods that will help NASA make better choices for equipping its mission? A forthcoming SFI working group, "Lookahead optimization in artificial and natural systems," will bring together scientists from diverse fields to develop better quantitative models of optimal decision making. The interdisciplinary working group was conceived by SFI and MIT Postdoctoral Fellow Brendan Tracey, SFI Professor David Wolpert, and SFI Professor Mirta Galesic, who is Cowan Chair in Human Social Dynamics.

Tracey and Wolpert began planning the group when they discussed the limitations of current optimization algorithms, which tend to focus on immediate payoffs, rather than on the relative benefits of learning new information. "The value of lookahead optimization," according to Wolpert, "is that it gives us a way to formalize how agents gather and then exploit information. When aerospace engineers test airplane wings, they should not choose what to test next without accounting for what they will learn in their initial test, as the information they learn will affect *subsequent* choices of what to test." Lookahead optimization allows scientists to account for this kind of learning.

Galesic became involved in the workshop when she recognized that lookahead optimization may help us understand some seemingly odd patterns in individual and social decision making. "It can be hard for us to see how a decision might actually be optimal for a set of actors. Sometimes what does not look optimal — say, delaying an important decision rather than choosing what seems like a good solution right now — might actually make sense in a lookahead framework, which accounts for the long term consequences of immediate choices."

While Galesic hopes that the workshop will help her see where lookahead optimization might be used to understand and predict human decisions, Tracey and Wolpert hope to learn more from Galesic about how heuristics that humans and other animals use relate to engineering design. For Tracey, the working group is an occasion to clarify "the meeting ground between mathematical decision models and patterns in biological, social, and artificial systems." The workshop will take place at the Santa Fe Institute from February 21-22, 2018.

In January 2013, NASA scientists released 20 balloons in Antarctica to better understand and provide forecasts for weather in space. (Image: NASA Goddard via flickr)

Extending the modern evolutionary synthesis at SFI

This coming February, the Santa Fe Institute will host an international workshop to explore a more integrative approach to thinking about evolutionary biology. In 2016, SFI became one of eight institutions to receive a three-year, $8 million grant from the John Templeton Foundation. Together, the eight institutions hope to build an "extended" evolutionary synthesis.

When Charles Darwin published his idea of natural selection as a mechanism for the evolution of species, in 1859, he had no theory of inheritance. Natural selection acts on inherited genetic variation, but where that inherited variation came from was still a mystery.

Fast forward past the discovery of genes to the late 1930s, when geneticists and naturalists were locked in a battle over how evolution worked. The two groups ultimately resolved their differences with an understanding called the Modern Synthesis, which remains the formal foundation of our understanding of evolution.

The Modern Synthesis says, in essence, that natural selection drives evolutionary change by changing gene frequencies in populations of organisms. Genes, the founders of the Modern Synthesis said, were the source of all inherited information and, a decade later, the founders of molecular biology endorsed that view. The separation of development and inheritance, brought to prominence with the Modern Synthesis, was hailed as a major advance in evolutionary thinking.

But the idea that developmental experiences can have evolutionary consequences persisted. Extensive data have accumulated showing that diverse resources other than genes are transmitted from parents to offspring, including components of the egg, hormones, symbionts, epigenetic marks, antibodies, ecological resources and learned knowledge. Many researchers now attempt to integrate these components of development into their understanding of evolution through an extended conception of evolution. What is transmitted are the developmental means to reconstruct life cycles, raising the possibility that non-genetic mechanisms of heredity can contribute to the evolutionary process in ways that standard conceptualizations struggle to accommodate.

Now biologists have returned to this century-old question with new tools, new ways to think about biological information and renewed vigor. SFI, with its emphasis on complexity and interdisciplinary approaches, is an important hub for the debate.

Workshop co-organizer Michael Lachmann, a theoretical biologist and Professor at SFI, is deeply involved in the development of the extended synthesis. Lachmann acknowledges there's pushback from some quarters. "We know the Modern Synthesis isn't exactly right, but is this enough of a reason to change the theory? Is it like friction in physics, which very often is ignored, or is it more like the photoelectric effect — a small deviation from theory that eventually brought about a profound change in physics?" Lachmann asks. "Many people see it as closer to friction—that the Modern Synthesis is a very useful approximation and there's no reason to change it."

Fellow co-organizer Kevin Laland (St. Andrews University), an SFI Science Board member, says: "The extended evolutionary synthesis is not a rejection of orthodox Darwinism, but rather an attempt to explore whether it is useful to think about the evolutionary process in a different way. The relationship between inheritance and development lies right at the heart of the contemporary debate."

The February workshop will include 30 to 40 researchers who will discuss the history of our understanding of inherited information and how epigenetic inheritance, cultural inheritance, and developmental processes complicate standard evolutionary theory. A second SFI workshop funded by the same grant is planned for November, which will discuss how developmental experiences bias evolutionary outcomes.

Cetonia aurata take off composition (Image: Wikimedia Commons)

ACHIEVEMENTS

SFI Professor **Cristopher Moore** and External Professor **John Rundle** (UC Davis) were named fellows of the American Association for the Advancement of Science (AAAS) for 2017. Moore was honored for his distinguished contributions to statistical physics and the physics of computing, particularly in the theory of networks, computation in physical systems, and quantum computing, while Rundle was honored for distinguished contributions to earthquake forecasting and hazard analysis research, for both natural and human-induced seismic activity.

In a list of "100 articles every ecologist should read," the journal *Nature Ecology and Evolution* included fifteen articles authored or co-authored by SFI researchers. **Robert Axelrod** (University of Michigan), **James Brown** (University of New Mexico), Science Board member **Simon Levin** (Princeton University), Science Board member **Robert May**, (University of Oxford), External Professor **Van Savage** (UCLA), and Distinguished Professor **Geoffrey West** were among the SFI researchers recognized.

Aerial view of forest (Image: Michael Olsen)

Forging new tools for a complex world
Info-metrics working group

The fields of information theory, info-metrics, and complexity science are deeply interconnected. A working group, co-organized by Omidyar Fellow Andy Rominger and External Professors Amos Golan (American University) and John Harte (UC Berkeley), will explore new possibilities for applying the principles of info-metrics and information theory to dynamic complex systems in non-equilibrium states. The working group will run March 15 and 16.

"Info-metrics," a term coined by Golan, is "the science of modeling, reasoning and drawing inferences in conditions of noisy and insufficient information." The tools of info-metrics and information theory can be useful to describe complex systems, particularly when they are in a steady state and when they scale up in predictable ways.

But can those same tools be applied to dynamic complex systems, or systems where a micro-scale looks very different from the macro-scale?

"The concept of maximum entropy, for instance, works well for steady-state systems. But in social and behavioral and environmental sciences, most systems are progressing all the time," says Golan. "So the question is: how can we model it, and can concepts from information theory and maximum entropy theory help us in modeling systems farther away from equilibrium?"

The field of ecology offers examples where an information-theoretic approach often fails, especially as a study moves from the micro-scale to the macro, says Rominger. "If you look at spatial configurations of populations at a coarse grain in a steady state, you might see a reasonable approximation. But as you scale up, there are non-linearities."

The working group will explore possibilities for modifying the inferential tools of information theory and info-metrics that might better describe the dynamics of rapidly changing complex systems that scale in non-hierarchical ways.

NSF awards SFI $500,000 to study origins of life

To an amazing extent, we know how life on Earth evolved from the earliest primitive cells. But exactly how those first primitive cells formed is one of the great open questions of science. Breaking the field free of entrenched disagreement may require a fresh start and a critical mass of expertise from sciences as diverse as physics, geochemistry, biochemistry, mathematics and astrobiology.

In August, the National Science Foundation awarded SFI a half-million dollar grant to help fashion and operate a research network for exploring questions around life's origins. The five-year project will be led by two SFI principal investigators: Omidyar Fellow Chris Kempes and President David Krakauer.

SFI is an ideal place for this work partly because of the institute's long history of studying origins of life questions and partly because of its expertise in facilitating interdisciplinary work and synthesis.

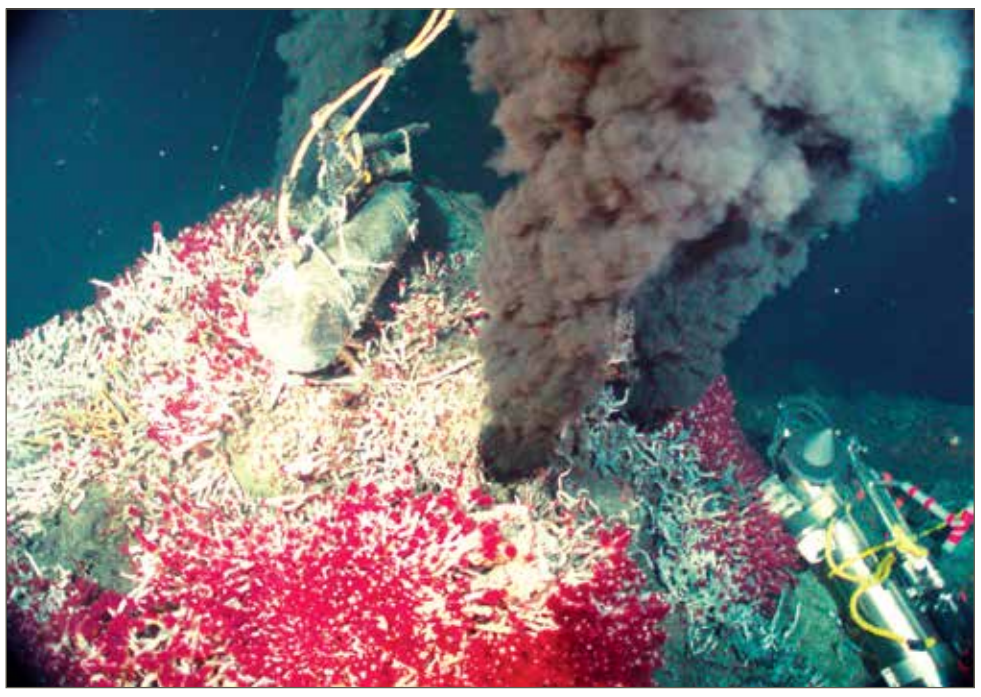
"Origins of life is one of the best examples of a discipline that really requires a large number of players in terms of perspective, expertise and knowledge," Kempes says.

According to Krakauer, the origins of life "can be thought of as the ideal test case for exploring the interfaces of physics, chemistry and biology."

Although SFI collaborates with experimentalists, theoretical questions are where the institute shines. For example, says Kempes, SFI-affiliated researchers might ask, "'Do you always need a certain type of formal informational system [such as DNA] for life to thrive and evolve greater complexity?' Those kinds of questions open up a big window for various types of theory to come in."

"We're exploring the nature of interactions between generality and contingency, or the universality of conservation laws versus the apparent rarity of adaptive information," Krakauer says, "and we ask these rather grand questions in relation to the tangible challenges of evolving replication-translation mechanisms."

The new Origins of Life Research Coordination Network (RCN) will facilitate meetings and build a virtual online hub for collaborations, discussion, and educational resources. Next summer, the RCN will kick off its work with a meeting of 30 to 40 experts to assess the state of the field and identify ripe questions for research as well as areas unknown.



Chemical processes support life around an undersea hydrothermal vent. (Image: National Oceanic and Atmospheric Administration)

Finding meaning in big data

Big data gets a lot of attention. Fields ranging from cybersecurity to cancer biology to social networks increasingly use behemoth datasets, which can be seen as vast networks. Researchers search those networks for patterns and connections that could help solve problems: Stop hackers, lengthen survival, improve communication.

But there's a challenge. The noise in high-dimensional datasets can obscure real correlations — and give rise to illusory patterns that don't mean anything.

In the case of biology, for example, a researcher may sequence the genomes of 100 mice and analyze tens of thousands of genes. That's a lot of data, but the amount of information per gene — the number of mice — is relatively small. When researchers analyze that dataset, they may find spurious correlations, or connections that occur by chance, between genes and disease risk.

"Humans are very good at seeing patterns, even when they're not there," says Cristopher Moore, Professor at SFI. "We have a strong tendency toward false positives. Our algorithms do, too."

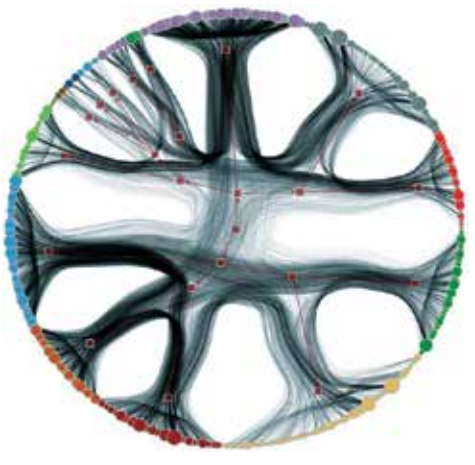
To better understand the limits of finding meaningful patterns in big data, Moore has organized a working group, to be held at the SFI April 2-5. He's invited an interdisciplinary group of mathematicians, physicists, and theoretical computer scientists to address the problem and devise new algorithms that can succeed all the way up to the limits that arise from not having enough data, or not knowing if the data is accurate.

> "Humans are very good at seeing patterns, even when they're not there."
>
> —CRIS MOORE

Moore suggests that networks can undergo a phase transition of sorts, shifting from order to disorder, similar to how ice melts or iron demagnetizes. At low temperatures, the magnetic fields of the atoms in a block of iron mostly align in the same direction. Raise the temperature enough, and the iron's magnetic strength abruptly drops to zero.

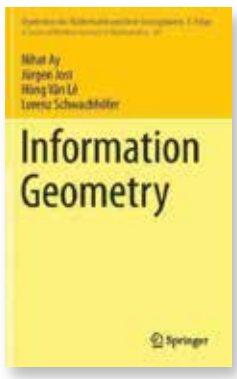
That analogy extends to networks. With enough information about each node — for instance, when a node has links to similar nodes — a network can readily be classified into groups of similar members. But if you add noise by adding nodes with incomplete information or unexpected connections, eventually the noise overwhelms the signal. It becomes impossible or unfeasible to find meaningful patterns.

Recognizing the inherent limits of finding meaning, says Moore, can help researchers map out the difference between real patterns and illusory ones.



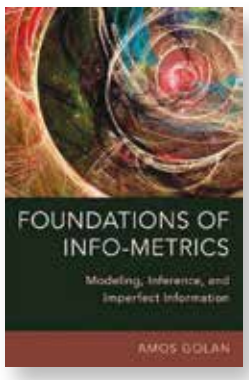
A network of political blogs, subdivided into groups of similar members. The researchers' technique allowed them to divide into subgroups, stopping the subdivision process when no statistically meaningful subgroups remained. Divisions could correspond to real-world distinctions such as Democrats or Republicans, Labor Democrats or environmental Democrats, etc. (Image: Zhang and Moore, 2014)

New books by SFI authors



Information Geometry (Springer 2017) by SFI Professor Nihat Ay, External Professor Jürgen Jost (Max Planck Institute), Hông Vân Lê (Czech Academy of Sciences), and Lorenz Schwachhöfer (TU Dortmund University) will become the standard reference for the eponymous branch of mathematics. The book provides a comprehensive introduction and a novel mathematical foundation for the field of information geometry, with complete proofs, background material, and application highlights.

Written for scientists who are interested in the mathematical foundations of complex systems, the text will also appeal to statisticians and mathematicians who are interested in geometry, information theory, or the foundations of statistics.



Foundations of Info-Metrics: Modeling, Inference, and Imperfect Information (Oxford University Press 2017) by SFI External Professor Amos Golan (American University) offers an overview of info-metrics: modeling, reasoning, and inference in conditions of noisy and incomplete information. We often don't have all the information we need to make a decision, so we find solutions derived from the information available and a choice of inferential procedure. Golan's book lays out a number of real-world, multidisciplinary case studies where a simple, general framework of info-metrics helps optimize predictions and decision-making.

What are humans good for?

Members of SFI's Applied Complexity Network (ACtioN) confronted this question again and again over the course of the November symposium on natural and artificial intelligence.

In the most pessimistic interpretation, the answer is: not much. Machines beat us in chess in 1997 and now, in 2017, in the notoriously complex game of Go. Algorithms are producing nostalgic playlists, tweeting prolifically, designing fonts, and co-authoring scientific papers. And although their sonnets remain stilted for now, robots' weather and sports reports have become the norm, whether we realize it or not.

Of course, there are also algorithms that spend their days massaging cat photos into the form of a loaf of bread. But even these are a fertile breeding ground for machine learning, suggests Y Combinator's Michael Nielsen. The real question isn't what computers can *do*, but rather what computers are *for*. Are they simply machines for answering questions — what Nielsen terms "cognitive outsourcing?" Or can machines actually change the range of thoughts that we can think? Can they *transform* our cognition?

Since long before the days of dunce caps, we have associated *intelligence* with computation powers far more than with kinesthetic or emotional abilities. But SFI President David Krakauer offered an alternative definition: "Intelligence," he declared, "is making hard problems easy."

(Image: Francesco Romoli)

The simple act of walking across a room without having to think about each step represents a form of intelligence, according to SFI Professor Nihat Ay. His research group is building a theoretical framework for understanding "embodied intelligence," which could one day be used to re-create natural movement in robots. For humans, this form of intelligence emerges from a learning process — a self-organized interplay between brain, body, and environment. Robotics, by contrast, is still dominated by the paradigm of pre-programmed control from a central computer.

Machines do not experience the open-endedness of *childhood* — a developmental period which, arguably, is responsible for making us human. Most machines learn using human-generated datasets. Even AlphaGo, which was *not* trained using human data, still operates entirely within the game's rigid parameters.

As External Professor Melanie Mitchell (Portland State University) pointed out, babies spend all their time simply discovering the physical world around them — touching, drooling, biting, and developing common sense. AI can beat us at Go, but it can't tell us "whether Michael Phelps' hair was wet when he got out of the pool."

"In robotics, you get regularly humbled by the real world," says Philip Heermann, who attended with Sandia National Labs. Things that come naturally to humans — sitting, walking — are often comically difficult to replicate. But should we be replicating them? Or splitting our tasks?

If humans were only ever good for playing Go, tweeting, and recognizing voices, there wouldn't be much use for us anymore. The key now, it seems, is to play to our strengths: problem-solving, innovation, and play. Esther Dyson (Way to Wellville), a former SFI Trustee, remarked, "I would like to see all of those truck drivers become gym teachers and soccer coaches, and pay gym teachers and soccer coaches more."

Technically, we've been commandeering "other" — if not "artificial" — intelligence for millennia. We took a hard problem — traveling fast, carrying heavy goods — and recognized that it was not our strong suit. We domesticated the horse. And here we are today.

ACtioN-ABLE INSIGHTS FROM ATTENDEES

"Having the common language of complexity is key for articulating, sharing, and identifying problems, even on a small scale."
—Visual artist Kiyomi Baird

"Algorithms are sexy, but insight actually comes from as many iterations [of neural networks] as possible."
—Mark Johnson of Descartes Labs

"In robotics, you're regularly humbled by the real world. We were managing complexity and we didn't even know we were."
—Philip Heermann of Sandia National Labs

SFI ON arXiv

Learning by omission

While scientists don't fully understand how machine-learning algorithms have succeeded at "intelligent" tasks like image and speech recognition, they do know that in order to generalize, an algorithm has to remember the important information while forgetting the useless. This idea, often referred to as an "Information Bottleneck," has generated a flurry of research since it was first proposed in 2000.

Only very recently, however, has this idea been applied to the rapidly developing field of deep learning, i.e., machine learning that uses so-called artificial neural networks. What would happen if neural networks were explicitly trained to discard useless information, and how to tell them to do so, is the subject of new research by SFI Postdoctoral Fellows Artemy Kolchinsky, Brendan Tracey, and Professor David Wolpert.

"It may be that deep learning networks succeed because of what they learn to ignore, not just what they learn to predict," Kolchinsky says. "So we ask: what happens if we explicitly encourage a network to forget irrelevant information?"

In their most recent paper, published on the arXiv preprint server, the scientists present a method for training a machine learning algorithm to identify objects using minimal information. The method resolves the problem of how to estimate the amount of information stored in the algorithm by making use of a novel estimator, published this past July by Kolchinsky and Tracey in the journal *Entropy*.

"The motivation for this paper is to make predictions using data from a bandwidth-limited environment," says Tracey. "Say you're a satellite in space, or a remote weather station in Antarctica. You can't send back all of the data you collect, so which pieces of data are the right data to transmit?"

More generally, the method could be used to push networks to learn more abstract and more generalizable concepts, potentially leading to better performance on new data — from recognizing pedestrians near self-driving vehicles, to reporting a five-day weather forecast from Mars.

McKinnons give $3 million *(cont. from page 1)*

tists, scholars, intellectuals, and artists who collaborate with the institute's 12 resident professors and ~15 postdoctoral fellows. The Institute also offers summer schools, internships, and free online courses to train the next generation of scientists in concepts and techniques for studying complex adaptive systems.

Sonnet and Ian McKinnon (courtesy the McKinnons)

In 2015, the McKinnons donated $2.5 million to endow the Institute's education and outreach programs. The McKinnons both hail from New Mexico and are long-time supporters of SFI, the University of New Mexico, and Ian's high school alma mater Albuquerque Academy.

Their gift to the Santa Fe Institute coincides with another donation from SFI Trustee Chairman Emeritus Bill Miller to support renovations, upgrades, and programming at the Institute's second campus in Tesuque, NM. The 36-acre estate was donated to SFI in 2013 by Eugene and Clare Thaw, who intended it to serve as a contemplative space to host visiting scientists and scientific meetings. Three-million of Miller's total gift of $5 million will allow SFI to fully realize the potential of a second campus dedicated to the application and cultural impact of complexity science.

"These synergistic gifts from the McKinnons, the Thaws, and Trustee Emeritus Bill Miller allow us to expand our research ventures further into the unknown," says Krakauer. "There's an open creativity that emerges when brilliant, trained, and unconventional minds come together in an environment optimized for collaboration. We've seen a cascade of scientific innovations result from our unique workshops and working groups, and with this new material support, we're banking on some very exciting discoveries in the near future."

MORE ABOUT THE MCKINNONS

Ian and Sonnet McKinnon both grew up in Albuquerque, New Mexico. Sonnet attended UNM Anderson and graduated with a BBA. Ian graduated summa cum laude and Phi Beta Kappa from Occidental College with a BA in Public Policy and received an MBA from Harvard Business School as a Baker Scholar.

Ian is the Founding Partner of Sandia Holdings, LLC, the primary investment vehicle for the McKinnon family and related entities. Prior to founding Sandia, Ian spent nearly twenty years at Ziff Brothers Investments, from which he retired as a Managing Partner. Outside of the office, Ian serves as a trustee of the Brunswick School in Greenwich, Connecticut, where he also chairs the Investment Committee. He is a trustee of the Albuquerque Academy and the Santa Fe Institute and serves on the Advisory Board of HighVista Partners, a money management firm in Boston. Finally, he is one of the founding partners of TEAM8, a sports management company.

Sonnet served as National Vice-Chair for the UNM Foundation Board of Directors from 2006-2010. She was also a mentor and board member for REACH Prep, an organization that provides academic and other forms of assistance for underprivileged students who are applying to and matriculating in private preparatory schools. She has served on the board of Greenwich Academy since 2013 and has acted as President of the Board of the Roger Federer Charitable Fund Inc. since 2014.

Ian and Sonnet live in Greenwich, CT with their two children, two dogs, rabbit, and fish.

Two new trustees elected to SFI's Board

The Santa Fe Institute's Board of Trustees has welcomed two new members. Bill Gurley of Benchmark Capital and James Pallotta of Raptor Group were elected to the Board during the Institute's annual Applied Complexity Network and Trustees Symposium on November 5, 2017.

A long-time venture capitalist, Gurley has drawn inspiration from complexity science throughout his career.

New trustees Bill Gurley and James Pallotta

"In 1993, I was fortunate enough to begin a career on Wall Street and was seated near Michael Mauboussin, now the chair of the Board of Trustees at the Institute. We both shared a fascination with learning, and shortly after we met we both consumed Mitchell Waldrop's *Complexity*, [a book] about the rise of the Santa Fe Institute. SFI External Professor Brian Arthur's work on increasing returns and his essay in *Harvard Business Review*, edited by Cormac McCarthy, were mind-blowing," Gurley recounts. "I often tell people that this single book has had a bigger impact on how I think about the world than anything else I have ever read. The concepts that I "borrowed" from *Complexity* and SFI have been alongside me for my entire venture career, and have played a key role in how I think about markets, strategies, and competitive advantage. I couldn't be more excited about joining SFI as a trustee."

Gurley has spent 18 years as a general partner at Benchmark, joining in 1999. Over his venture career, he has invested in and served on the board of such companies as Jamdat (IPO: JMDT, Acq. by EA), GrubHub (IPO: GRUB), Nextdoor, OpenTable (IPO: OPEN, Acq.by Priceline), Stitch Fix, Uber, and Zillow.com (IPO: Z). Before entering the venture capital business, Gurley spent four years on Wall Street as an "Institutional Investor" ranked research analyst, including three years at CS First Boston. He also worked as the lead analyst on Amazon's IPO.

Pallotta is founder, chairman, and managing director of the Boston-based Raptor Group, a diversified financial services firm that provides investment management and advisory services. In his portfolio management role at Raptor Capital Management LP, he manages individual, institutional, and his own personal capital.

He is President and Chairman of the professional Italian football club AS Roma, as well as co-owner and executive board member of the Boston Celtics. He is known for his philanthropy, giving millions each year through his charitable trust.

"It is a pleasure to formally welcome Bill and Jim to the SFI community," says Michael Mauboussin, Chair of SFI's Board of Trustees and Director of Research at BlueMountain Capital. "These are legendary investors with deep intellectual curiosity. They appreciate the importance of rigorous research in complex systems that defies disciplinary boundaries. We are very excited to have them on the board."

The Santa Fe Institute's Board of Trustees, which has fiduciary responsibility for the Institute, oversees SFI's operations through its biannual meetings and its active committees that offer advice and support to SFI's leadership.

**Visit www.santafe.edu/trustees for complete biographies*

Complexity postdocs reconvene in March

The Santa Fe Institute and James S. McDonnell Foundation (JSMF) are reconvening their postdoctoral fellows for the third bi-annual Postdocs in Complexity Conference on March 27-30 in Santa Fe. The conference is generously funded by JSMF.

During the four-day postdoc conference, early career complexity scientists share ideas and collaborate on projects, and learn from researchers from within the SFI and JSMF communities and the corporate world.

This year's talks will revisit several themes from previous conferences and introduce new topics, like SFI External Professor Michael Hochberg's talk on academic publishing.

"Although early-career scientists may already have authorship experience, it can be highly challenging to navigate the world of scientific publishing," says Hochberg, who is also the founding editor of *Ecology Letters*. His talk will explore what scientific journals are looking for and how they function, strategies for getting work published, the use of social media, and what to expect in the future of publishing.

The postdocs will also meet for four research jam sessions, working in small groups to tackle research questions. But unlike previous meetings where groups rotated through different topics, this year's groups will each focus on a single topic.

"There was a desire to have more goal-oriented research exercises," says Hilary Skolnik, SFI's Postdoctoral Fellows Program Manager. "The goal for this year's research jam sessions will be to work toward producing something substantial, like papers for publication or proposals for funding."

JSMF and SFI postdoctoral fellows convened in Santa Fe for their second joint conference in July, 2017

Researchers turn to complexity science to improve assessment of scientific value

It's difficult to put a value on scientific research. In the last two or three decades, universities and other institutions have increasingly turned to quantitative metrics to gauge the impact of research. An individual's h-index, for example, reports that a scholar with an index of h has published h number of papers each of which has been cited at least h times. Google Scholar also reports an i10 index, which shows how many publications have been cited at least 10 times.

Journals have a citation-based metric, too — the impact factor (IF). Yet another, Altmetrics, uses social media shares and likes, together with citations, to assess the reach of a published paper. Important decisions may turn on these measures: They influence how an individual is promoted or evaluated for tenure within a university, for example, or whether or not a project gets funding.

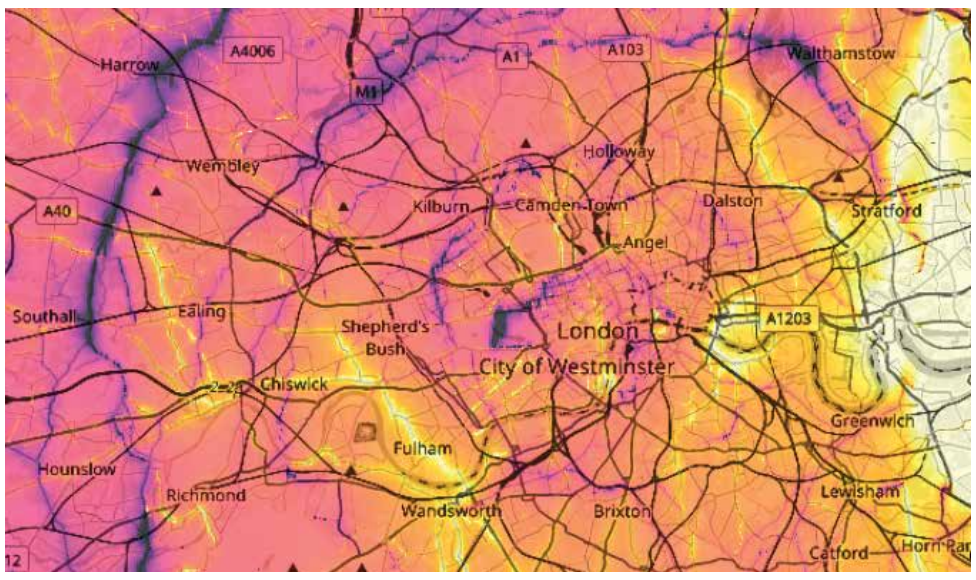
To Manfred Laubichler, a biologist at Arizona State University and an SFI External Professor, the increased reliance on these metrics is a worrying trend. That dependence risks collapsing judgment and impact. "We have basically outsourced what is the core activity of science, namely to judge the future direction of science," he says. These metrics may fail to recognize novel ideas or innovative approaches, especially in interdisciplinary fields that aren't easily categorized.

Laubichler and SFI President David Krakauer suspect that the tools of complexity science can help. They've organized a workshop, scheduled for early April at SFI, designed to explore questions about scientific value. "The goal is to basically first get some clarity about what we actually mean by impact, and what judgment means, in the context of the type of science we are pursuing at the SFI," Laubichler says.

The workshop will bring together researchers in complexity science with institutional leaders to start a conversation about reframing the problem of measuring impact. Laubichler says the group will look to the tools of complexity for insights into how to improve judgment.

Laubichler hopes the discussion will spur ideas about new ways of measuring value. "We'll be attempting to find creative new metrics that actually represent the values we advocate for in the kind of work we're doing," he says.

RESEARCH NEWS BRIEFS



A map of London, colored to show the distortion of travel the routes through a central point. (Image: Hugo Serrano (University of Rochester), co-author of "Morphology of travel routes and the organization of cities" with Hyejin Youn)

THE CITY CENTRAL

How can we tell if a city is centralized? Hyejin Youn (Northwestern University), a former SFI Postdoctoral Fellow, and her co-authors on a new paper in *Nature Communications* offer a way to quantify city centralization by looking at geometric shapes of travel routes. That geometric shape can curve inward when there is a positive force at the center to attract the edges; it curves outward if a negative force at the center repels. It's an example of social physics, says Youn — like observing the deflection of sunlight by gravity to prove the general relativity theory, we can observe human mobility as it responds to a force, or positive externality, revealed by infrastructure, like roads.

VIVE L'INNOVATION

As the first parliament of the French Revolution navigated its way into a new democratic system of governance and out of monarchy, more than one thousand speakers debated how to reinvent the relationship between individuals and the state. In a paper published in October on the arXiv preprint server, SFI External Professor Simon DeDeo (Carnegie Mellon University) and co-authors analyzed reconstructed transcripts from the 40,000-plus speeches made in early years of that parliament. Using new techniques in information theory that draw on social science, the authors tracked how new speech pattern and novel ideas arose while old patterns faded from the discussions. The paper was listed in *MIT Technology Review*'s "Best of the Physics arXiv" for the week of October 28, 2017.

NEW TOOLS FOR STUDYING ANIMAL SOCIALITY

Somewhere between million-node social media networks and the dozen nodes of a wolf pack, there's a little-explored sphere of social experience. In their recent *Animal Behaviour* paper, SFI-ASU Postdoctoral Fellow Elizabeth Hobson and co-author David McDonald (University of Wyoming) developed network analysis tools to explore how relationship strengths vary across micro, meso, and macro levels of animal sociality — for example, between an individual and its community, or between a community of individuals and the social network of the entire group. The new tools, adapted from population genetics, could allow researchers to understand whether differences in social environments experienced by a particular animal are the result of individual quirks or are general characteristics of the social organization. The authors successfully applied their metrics to data from three known animal social networks and discussed how their innovation offers a quantitative method to study disease transmission, social complexity, and the flow of information in animal social networks.

COUNTER-INTUITIVE COARSE-GRAINING

The Blackwell order in information theory considers two channels that convey the same information — for example, two phone lines — and states that if one channel's output is a garbled, or noisier, version of another's, then that channel is "Blackwell inferior," and therefore typically less capable. There have been some known exceptions to this rule, but in their *Entropy* paper, SFI Professor David Wolpert and co-authors present an even more surprising one: They show that pre-garbling a signal through coarse-graining — a process of simplifying a signal that usually results in a loss of information — can actually lead to a superior channel. This discovery offers important new insights for the development of measures of unique information.

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Graduate Workshop 2012 (Image: SFI files)

The 2018 SFI Alumni Fiesta

Calling all former SFI postdoctoral fellows, REUs, Summer School students, and faculty! We're hosting a reunion, and we hope you can come.

Thirty years ago, in the summer of 1988, the first Complex Systems Summer School was held at the base of the Sangre de Cristo Mountains, marking the beginning of SFI Education. In the three decades since, roughly 4,000 aspiring scientists have gained experience through SFI's fellowships and face-to-face educational programs.

To celebrate, we're planning the first SFI Alumni Fiesta, July 6-8. It will be a chance to reconnect in Santa Fe, meet people from other programs, and share some big and creative ideas.

"It's a combination reunion, conference, networking event, and collaboration space," says Paul Hooper, Director of Education, a former Omidyar Fellow and summer school alum. "It's also an opportunity for SFI to check in with our alumni and take stock of the impact our programs have had."

We'll kick off the Fiesta with a reception at SFI and continue with two days of talks, exchange, and collaborative events in Santa Fe. Hooper hopes these interactions will offer opportunities for alumni to share current work, brainstorm nascent ideas, and spur new collaborations.

"This event is really about connecting people and supporting the community of folks interested in complexity science," says Hooper.

The Fiesta will follow immediately on the heels of the 2018 Complex Systems Summer School, and participating students are encouraged to stick around for the fun.

Alumni can watch for a Save-the-Date invitation and a link to pre-register for the Fiesta — if we don't have your current email address, just reach out to us at santafe.edu/alumni!

Parallax

Winter 2017-18

THE NEWSLETTER OF THE SANTA FE INSTITUTE

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RESEARCH NEWS BRIEFS

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FORECASTING FUTURE FLU

By combining epidemiological data with information about the how the influenza virus has evolved, SFI External Professor and Science Board Co-Chair Mercedes Pascual (University of Chicago) and co-authors accurately forecasted the overall number of flu cases for the 2016-2017 flu season before the season began. The authors say their model, published in *Science Translational Medicine*, complements existing quantitative methods for forecasting seasonal flu by considering evolutionary change in the virus and achieving longer lead times than previously possible.

BETTER MIGRATION MODELS THROUGH PHYSICS

Animal migration is at the heart of complex systems — diverse groups of interacting creatures move together, often across great distances, sometimes for long and/or cyclical periods. Yet, until now, most migration research used tracking data to evaluate how external environmental factors affect movement. Physicist Christopher Revell (University of Cambridge) and zoologist Marius Somveille (University of Oxford) built a physics-inspired model of bird migration that offers a novel bird-centric explanation. Their model holds up to other models of the Black-browed Albatross, is likely applicable to other birds, and even predicts paths and destinations. This *Nature Scientific Reports* paper began as a project by the authors at SFI's 2016 Complex Systems Summer School.

A COMMON PATHWAY FOR COMPLEX SOCIETIES

The world today is populated by large, sophisticated, densely populated, and technologically advanced nation-states. How did such complex social formations arise? A new article published in the *Proceedings of the National Academy of Sciences* offers a systematic look at how some 400 complex societies from around the world have developed over the last 10,000 years. The work is the result of years of research conducted by the Seshat research group— an international team of evolutionary scientists, historians, archaeologists, and anthropologists that held one of its initial meetings at SFI. By statistically analyzing the database they created for large-scale analyses of cultural evolutionary processes, the investigators were able to pinpoint a single dimension of 'social complexity' that can meaningfully measure the developmental trajectories of all the societies explored in the sample. While most previous studies focus on only one or two 'primary' characteristics to explain social development, this novel finding shows that social development requires an intricate co-evolution of numerous, seemingly disparate traits — from the size of the society to its economic sophistication, administrative capacity, informational technology, and others.

Santa Fe Railyard Plaza tilt-shift drone capture by Stephen Guerin (Image composite by Laura Egley Taylor)

The first annual InterPlanetary Festival

Santa Fe Institute's first annual InterPlanetary Festival will draw space enthusiasts from around the world for a two-day celebration of human ingenuity June 7-8, 2018, in Santa Fe, NM. The festival will transform the Railyard District in downtown Santa Fe with an expo showcasing innovation and technology for space exploration.

Concurrent with the expo, participants can enjoy open-air concerts, maker spaces, lectures, panel discussions, food, beer, and citizen science projects and games centered around InterPlanetary topics.

"This is a festival where we're asking people to come and have fun, but also to contribute towards a global challenge of becoming an InterPlanetary civilization," says SFI President David Krakauer.

As a global destination for both the arts and sciences, Santa Fe is the ideal location for a festival that celebrates innovation across these domains. The InterPlanetary Festival coincides with the opening of the CURRENTS New Media art installation and the inaugural Nation of Makers Conference (NOMCON) in Santa Fe.

"The arts — visual arts, cinematic, literary, musical — expand our imaginations and they explore territories that we don't even know exist." Art, he says, plays a critical role in the InterPlanetary Project.

"We now as researchers need to reach out to a broader base in order to address complex issues such as resource use, economic inequality, and climate change," Krakauer says. "One way to bring people together is to make the science very aspirational. Posing an InterPlanetary challenge brings the best minds to the table and also has the virtue of potentially producing an InterPlanetary civilization."

If you or your organization would like to support or be involved in the 2018 inaugural InterPlanetary Festival, please contact Caitlin McShea at cmcshea@santafe.edu or call 505.946.3651