How do collective effects shape crypto networks?

From currencies like Bitcoin and Ethereum, to user-centric social networks, to new modes of governance, such as Decentralized Autonomous Organizations (DAOs), “crypto networks” consist of individuals who agree to follow a shared set of rules. They represent a huge natural experiment. At first glance, elephants and bacteria appear to have little in common. They differ in size, habitat, life span — everything, really. The two organisms do share at least one trait, though: they operate at different scales, and are governed by different mechanisms. elephants and bacteria operate in rarefied settings. They operate in the wild, are built by their users, and have to evolve by trial and error or with game-theoretic toy models — an approach that SFI Professor Jessica Flack says “works well in rarefied settings. But crypto networks don’t operate in rarefied settings. They operate in the wild, are built by their users, and have to work at scale.”

As such, the entire crypto space is a tangle of rule sets, evolutionary strategies, and economic propositions. What can more subtle, quantitative methods offer the study and design of these networks? What insights can we draw from wild-born, natural systems, such as brains and insect swarms, to better understand and implement collective smarts at a planetary (even interplanetary) scale? To start addressing these and other pressing questions raised by the proliferation of new crypto networks, SFI will host a workshop on “Collective Crypto” June 13, immediately before the InterPlanetary Festival. Organized by Flack, along with SFI President David Krakauer, Omidyar Fellow Joshua Garland, Trustee Graham Spencer of Google Ventures, and Dan Moroz of Harvard, the workshop will convene a necessarily diverse array of experts from academia and enterprise, bringing software developers and crypto token designers into collaboration with social scientists, evolution-ary biologists, collective computation theorists, and systems-thinking venture capitalists.

This group will cast its questions wide: How much agreement is required to produce intelligent collective action? Are there mechanisms that allow consensus to emerge that also maintain diversity of opinion? How might a DAO or public ledger change under the influence of different algorithms for the way agreement is encoded in the network? Flack seeks opportunities for the crypto ecosystem to inform the science of collectives as well. “How can decentralization be operationalized and measured?” she asks. “Is decentralization about how the information is integrated, or about how components contribute to aggregate function?”

Taking a MACRO view of the microbiome

At first glance, elephants and bacteria appear to have little in common. They differ in size, habitat, life span — everything, really. The two organisms do share at least one trait, though: Both are influenced by the biotic and abiotic environment around them and reciprocate by shaping their surroundings. Whether the focus is an elephant roaming an African savanna or a bacterium residing in the human gut, ecologists strive to understand this dynamic exchange between organism and environment.

However, elephants and bacteria operate at different scales, and are governed by different physical processes. As a result, the fields of macroecology (studying ecosystems of organisms visible to the eye) and microbial ecology (studying ecosystems of microorganisms, such as the human microbiome) have evolved differing theoretical approaches and experimental methods. “These fields have historically been quite separate,” says Carolina Tropini, a James S. McDonnell fellow at Stanford University and soon-to-be assistant professor at the University of British Columbia. “There is a lot of theory that has been developed in both, particularly in macroecology, that has not been applied to the microbiome.”

Tropini is helping to organize a working group at SFI May 8–9 that will attempt to link the two branches of biology. The other organizers include Britt Koskella, an evolutionary biologist at the University of California, Berkeley; Andrew Hryckowian, a microbiologist at Stanford University; and SFI External Professor Elhanan Borenstein, a computational biologist at Tel Aviv University.

The meeting, “Macroeological Insights into Microbiome Resilience and Function,” is intended as a starting point for a continuing conversation between the macro and micro worlds. The event will lay the groundwork for collaboration by identifying common challenges, parallels, and differences in theory and application.
This summer marks the 25th anniversary of SFI’s Graduate Workshop in Computational Social Science and Complexity. The annual two-week workshop, held this year June 16-28, brings together a group of advanced graduate students and a small faculty for an intensive two-week experience. To learn what makes this annual event so special — and how it has evolved over a quarter century and more than 250 participants — we sat down with co-directors and founders John Miller and Scott Page. Both are SFI External Professors, and Miller also chairs SFI’s Science Steering Committee.

Q: What did this annual event start? A: We were very young! In 1994, we took the idea that science advances by fun and humor, and we decided the best way to engage people in the world is to make it fun. Our first event was a food web with small teams to excel through elite sports. His March 21 op-ed appeared online in The Atlantic. In a March 14 interview with The San Antonio Express-News, External Pro­fessor James Evans described how dissenting opinions lead to better Wikipedia entries. In separate research, Evans and his collaborators published a February 13 Nature paper examining the size of team in science. Their finding is that small teams tend to disrupt fields, while large teams tend to develop them, was reported in The Atlantic, The New York Times, and The Conversation. On February 12, the Santa Fe New Mexican’s “Radio café” podcast aired an interview with External Professor Ross Hammond about the synergistic epidemics of obesity, undernutrition, and climate change. His recently co-authored commission and policy brief in The Lancet made headlines in CNN, BBC, Reuters, The Guardian, and other major news outlets. Immending postdoc Stefani Crabtree and her collaborators were featured in The New York Times on February 8 for their study of how Aboriginal hunting players may have played a key role in stabilizing ecological networks in Australia’s Western Desert. Their recent study is part of SFI’s larger ArchaeoEcology project, co-led by Dunne and Crabtree.

Study: Human impact on ecosystems yields unexpected insights

When the Australian government relocated Martu hunter-gatherers from their Western Australia lands in the 1960s, no one could have predicted the massive impact their absence would have on the desert ecosystem. A new study led by Stefani Crabtree, a Santa Fe Institute Visiting Researcher, and her collaborators, published at the SFI way of doing science. And the last half of the workshop is devoted to individual projects that are presented at a conference on the last day.

Q: After all these years, what keeps you excited about this workshop? A: Every year in Santa Fe, albeit only for two weeks, we assemble the best in the world in computational social science and complexity. The students are amazing, and for most of them, it’s the first time they’re surrounded by other colleagues who, regardless of their field (and there are a wide variety), have similar interests in complex systems. A wonderful and collaborative research culture quickly develops among the participants.

Q: What has surprised you the most? A: We often find ourselves visiting former students in their faculty offices and see their “awards” from the workshop taped to their office walls. That’s so cool. We feel as though SFI reminded them that science should be fun!

The construction of the Martu fenced plot between the nomadic period (a) and the contemporary period (b) for the summer/season

From Gutenburg to Galaxies

Beyond Borders
At first glance, the workings of the retail world may seem simple. Companies sell goods that people want, and consumers buy them. But the must-have products and slick advertisements are an intricate network of supply chains, investors, markets, data, and consumers that come together to determine whether a retailer succeeds or fails. Complexity science, it turns out, has much to offer the retail sector, as well as the industry’s disequilibrium and social cost processes. Especially useful to the retail industry is network theory. “If you think about a physical retailer, it really is very well described by a network — you have to get goods to those places as efficiently as possible,” says Michael Mauboussin, Chairman of SFI’s Board of Trustees and Director of Research at BlueMountain Capital Management. “The traditional retailers have moved into e-commerce, and e-commerce has moved into physical stores,” Mauboussin notes. This shift makes a network analysis of the retail sector more challenging, but also increases the potential impact of this approach. Another area where complexity science could benefit the retail sector is in understanding how companies scale. SFI Distinguished Shannan Professor Geoffrey West’s work on scaling and company mortality could be applied to the retail sector, for example. “I’d be really curious to see if [company] mortality in retail is any different than in any other industry,” Mauboussin says. “Is birth, or death, different than in other industries — and if so, why? That’s important if you’re an investor.” Complexity science could also offer insights into some of the most elusive aspects of retail: How trends start and spread. One study, co-authored by former SFI Post-doctoral Fellow Duncan Watts, highlights how preferential attachment behavior can impact the popularity of songs. Newer work, co-authored by SFI External Professor Stefan Thurner, examines the interplay between elite-driven “top-down” changes in tastes and “bottom-up” changes driven by less socially prominent groups. SFI will delve more deeply into the complexity of retail in a September 11 Topical Meeting in San Francisco, CA. The meeting is organized by SFI’s Applied Complexity Network (ACTN) and will be hosted by Shopify. More information about SFI’s Applied Complexity Network and the September 12 meeting can be found online at santeafe.edu/ACTN

“Viewpoints collide in social reactors working group”

“Urban scaling explains everything!” It was a message pounced on by popular reviewers in 2017 with the publication of Scale by SFI Distinguished Shannan Professor Geoffrey West. But in academic circles, the theory has moved far beyond what West popularized in his book — and it has also provoked heated debates. “Many researchers, and especially urban economists, have loudly rejected the work,” says José Lobo, faculty in the School of Sustainability at Arizona State University. “The criticisms have been serious and have accumulated.” So far, the debate has been conducted in slow volleys through the pages of top journals. But this spring, dissenting voices will come together for the first time. SFI’s collaborative ethos often centers discussion that reaches across disciplinary lines. This meeting, which will be held at SFI May 15–17, extends that open-mindedness even further, inviting to the table some of the theory’s most prominent critics. Urban scaling theory is most famous for high-lighting the disproportionate growth in economic output and innovation when a city grows linearly in population. These “superlinear” findings, while easily hyped, are not necessarily novel, and detractors assert that urban scaling theory adds little to existing approaches by urban economists and economic geographers. Others question the robustness of reported scaling results or point out that it fails to identify its underlying generative processes. “It is not often that SFI convenes a meeting at which criticism of SFI-sponsored work is explicitly aired and confronted,” says Lobo, who is the event’s organizer and convener. “That is a crucial one, for if we are to advance in our understanding of urbanization we need to be clear that we are measuring the right thing.”

“Is birth, or death, different than in other industries — and if so, why?” Mauboussin says. “I’d be really curious to see if [company] mortality in retail is any different than in any other industry.”

Crypto networks (cont. from page 1)

Krakauer emphasizes the urgency and scope of the conversation, adding, “We have to be forced now to conceive of fundamentally new institutions that more accurately reflect empirical reality. We see this in the blockchain/cryptocurrency debate, which started out as a very local means of decentralizing banking services, and has become an entirely new way of thinking about accountability and trust.”

Cutting through the hype is a priority if these novel systems can be implemented as the platforms for vital social functions they were designed to be — and SFI, ever the homeaver, discipline-blurring research is an ideal place to ask these questions.

“A living inspiration? Working group to investigate cells as computers”

Computers puzzle energy. A big chunk of the money spent on computers pays for power, and an estimated four percent of the total energy consumed in the United States is used to keep our computers computing. Physicists have long been interested in understanding the physical laws that describe that tradeoff. What’s the thermodynamic cost of processing information? This isn’t just a question for physicists, though. It resonates with living systems, too, which have evolved to perform specific jobs with access to only limited resources. “Our brain requires quite a bit of food whether we think analogically or digitally, we have a hunger for information processing, akin to computing. Artificial, human-built digital computers are always out of equilibrium. They need a steady source of power to keep running. So it goes with cells. Without energy, they stop functioning and die — so equilibrium, for a living thing, is death. In the last decades, break-throughs in the rigorous study of systems far from equilibrium — a field called nonequilibrium statistical physics — have led to the development of new tools. Now, researchers from a range of disciplines can better analyze such systems, whether they’re used on our smartphones or keeping organisms alive. Notably, recent studies suggest that cells carry out some biochemical “calculations” at a level of efficiency orders better than modern, artificial computers. That comparison raises a number of provocative questions. Do efficient biological systems look like any existing ideas in computer science theory? How did they evolve such efficient ways of computing, and what can we learn from them? “Thinking of biological systems as computing or information-processing entities immediately begs the question. What do they actually compute? It’s an open question,” says Stadler. In an effort to start probing those questions, Stadler and SFI Professor David Wolpert have organized a working group. “Thermodynamic and Computational Efficiency in Cellular Chemical Reaction Networks,” to be held at SFI April 31–2. They’ve invited researchers from a range of disciplines — chemistry physics, molecular biology, mathematics, computer science — who are interested in investigating the connection between energy and information processing, or computing. The meeting may help researchers gain insights into whether or not living cells should be seen as inspirational for future low-power devices. Are cells more like vending machines with simple inputs and outputs and limited and functional devices? Or do their functions speak to a broad range of calculations? “One potential outcome,” says Stadler, “might be that biological systems are a very bad model for building computers. ”

Microbiome (cont. from page 1)

methodology across research areas. Eventually, this group aims to produce a synthesis paper. “The ultimate goal is to understand the complexity of natural systems,” says Tropini. “The real world is not divided into disciplines or scales, so it’s possible we need a connection between macroecology and microbiology.”

The scientists plan to discuss experimental, theoretical, and computational approaches in macroecology and microbial biology. They will also explore concepts of ecosystem resilience and function and how they change in the face of invasive species. Additionally, the meeting will tackle the challenges of defining new species, particularly in microbiomes, and how species interactions shape ecosystems.
The paper explores how leadership arises in groups of animals like schooling fish, flocking birds, and herding carnivores. Rejecting simplistic “follow-the-leader” explanations, the authors develop an “anatomy of leadership” that relies on several principal components from how leadership arises in a group to how distributed, long-lasting, and far-reaching a particular leadership scenario is.

DEDEO WINS COZZARELLI PRIZE
SFI External Professor Simon DeDeo and co-authors are recipients of the 2018 Cozzarelli Prize, awarded by the Proceedings of the National Academy of Sciences, for their paper “Individuals, institutions, and innovation in the debates of the French Revolution.” Each year, the Cozzarelli Prize recognizes six papers published within 2017 for their “outstanding scientific quality and originality.”

DeDeo and colleagues’ study used machine learning techniques to parse transcripts and assess speech patterns during the French Revolution as a makeshift assembly emerged to form a new government. The analysis of these speeches reveals how new ideas emerged and took root — or floundered.

ACHIEVEMENTS

GIZEM BACAKSIZLAR
In the past few years as social movements around the world have swept to similar challenges, Bacaksizlars have helped them spread, and have led to protests and sometimes to conflict. Gizem Bacaksizlar is intrigued by how groups of people make decisions to take action on social issues, and how widespread use of smartphones, access to the Internet, and the speed of social media has influenced anger. She uses agent-based modeling, natural language processing, and system dynamics for her work in computational social science.

Bacaksizlar earned her Ph.D. in complexity and software and information systems at the University of North Carolina at Charlotte. She joined SFI as a postdoctoral fellow in February 2019 and works with SFI Professor Mirkoele Geisic to investigate how emotions and opinions spread in online networks. Their project scrapes data from news sites ranging from The Atlantic and Mother Jones to Breitbart and The Hill to assess how different outlets cover a single social event, such as the 2016 U.S. presidential election and current protests in Charlottesville, Virginia. They also gather data from those news sites’ comments sections and from Twitter to analyze how individuals are sharing and interacting with the information online.

STEФANI CRABTREE
It may seem that the problems modern society faces — from climate change to mass migration — are intractable and also unprecedented. However, the archaeological record holds countless examples of humans responding to similar challenges, and of societies discovering solutions. Stefani Crabtree approaches archaeology with a computational and complex systems lens, using data and modern modeling techniques to study how humans have interacted with their ecosystems — as part of the food web and as environmental managers — and how they assessed and dealt with risk. She also looks for ways to detect social transitions and to describe the common ways that societies interacted with their landscapes across the globe and throughout history. “We are poised at a crossroads as a civilization, plagued by many of the same issues that our ancestors faced,” she says. “An understanding of our past will help us navigate our challenges and create a more sustainable future.”

Crabtree holds two Ph.D.s — one from Washington State University and another from the Maison des Sciences de l’Homme et de l’Environnement at the Université de Franche-Comté. She has worked extensively with SFI as a visiting researcher, collaborating with VP for Science Jennifer Dunne on the Archaeoecology Project, and as a panelist for the 2018 InterPlanetary Festival. She will join SFI as an ASU-SFI Fellow in June 2019.

DAVID KINNEY
To understand complex phenomena — to untangle the ways multiple variables work on a system and identify the mechanisms underlying a behavior — scientists build statistical models. But first, they must decide which details to include in their models, and which to leave out. This level of fine-grained choice affects how the models work and can choose a course of action accordingly without documenting every time the patient picked up a cigarette.

However, research into, say, quantum physics requires much higher granularity. “When we face chemical, biological, or economic choices, information about the quantum-level details of the relevant systems may not be worth anything to us as agents. Therefore, this information can be left out of our explanatory models,” says David Kinney, who is completing his Ph.D. in the philosophy of science and formal epistemology at the London School of Economics. Kinney’s research also looks for better ways to graphically express probabilities and uncertainty in modeling high-dimensional systems, including interval-valued probabilities and algorithmic measures of complexity.

As a postdoctoral fellow, he will continue exploring these questions with Moore. He plans to arrive at SFI later in 2019.

TYLER MARGHETIS
Human beings have a high capacity for abstract thought. We speak and write using metaphors, conceive of untouchable objects like the number five and the future, and create musical improvisation. This cognition occurs in a variety of nested complex systems — our own brains, through our bodies interacting in space, and across the sociotechnical systems we inhabit. And it sometimes underpins revolutions. An individual might have a religious conversion or mathematical insight, or an entire culture can shift how it uses language over time. Cognitive scientist Tyler Marghertis researches how human imagination and abstract thought emerge, what triggers regime shifts, and why it sets into new stable regimes. “What I’m doing now and am excited to do in the future is to apply a complex systems science of certainty and conviction, of insight and loss of faith, of mathematical discovery and artistic improvisation to get to a deeper understanding of the natures of the regimes and revolutions of abstract thought,” he says.

Marghertis holds a Ph.D. in cognitive science from the University of California San Diego and is currently a postdoctoral research scientist at Indiana University, Bloomington. He plans to join SFI in September 2019 as an Omidyar Fellow.

HELENA MITON
There are two main features that make human culture unique among other organisms. First, what emerges as culture is highly non-random, of all the objects, language modifications, and behaviors that emerge among the individuals, organisms, institutions, and innovation in the debates of the French Revolution.” Each year, the Cozzarelli Prize recognizes six papers published within 2017 for their “outstanding scientific quality and originality.”

DeDeo and colleagues’ study used machine learning techniques to parse transcripts and assess speech patterns during the French Revolution as a makeshift assembly emerged to form a new government. The analysis of these speeches reveals how new ideas emerged and took root — or floundered.

MEHRDAD MOHARRAMI
Random graphs are one tool researchers can use to make rigorous predictions about real-world networks that either lack data or provide an unwieldy data set. These models have been used for many years and in a variety of fields, but there are still plenty of opportunities to address open questions and mathematical challenges, and to develop theoretical proof and rigorous analysis for how and why these models work.

Moharrami, who is completing his Ph.D. in electrical engineering at the University of Michigan, is looking for ways to address these questions and to provide a rigorous analysis for the models already in use. Moharrami is a familiar face at SFI — during a three-month internship in the fall of 2018, he worked with SFI Professor Cristopher Moore on two research projects concerning Bayesian inference and discoverable patterns hidden in high-dimensional data.
To use the whole galaxy and perhaps the whole universe as our kindergarten in becoming InterPlanetary Citizens with a decent record of stewardship of our own world that would make us worthy to visit (or be visited by) another world.

all gone, Chris said. But then it took only half a billion years for those cells to become eukaryotes and acquire (greater) nuclei. So maybe it’s not such an easy transition. Remember, these are all necessary steps on the road to “communicative species,” which even eukaryotes are decidedly not.

Or are they?

Caleb in turn points out that we have no first principles, no fundamental theory of life in the way that we have such theories in physics. We know to a first approximation why shit happens in the world outside of biology. Where living things are involved, we do not. So we have no tools comparable to the ones in physics to predict the probability that life might arise. However, he points out, we do have another route to the answer and that is simply to figure out how to count the instances of life occurring in our galaxy. This might have been a silly suggestion just a few years ago, like suggesting that the way to understand the human brain was to expose it and watch its gears turn.

Of course, that’s exactly what technologies such as Magnetic Resonance Imaging have allowed us to do, and when it comes to exoplanets, planets as planets outside of our solar system are called, we have now begun to develop the technology not only to see planets around other stars but to measure what in their atmosphere.

Chris says, “We now have a much greater sample of environments in which we might be able to look for what we call biosignatures—signatures of life.” In other words, we are systematically working toward detecting whether or not someone is passing gas on another planet. That’s the only way to put it that captures its essence. We’re looking for methane. And oxygen, too. And some other stuff.

In 2000 NASA plans to launch the James Webb telescope, which will greatly increase the probability of detecting methane on distant planets. And Caleb believes that within a year or two of that launch, we could begin to see signs of life. And within a decade, we should be able to say something about the probability of life anywhere at all.

Chris brings it full circle to point out that what we learn about the dynamics of exoplanets can inform our quest to manage our own planet more intelligently with respect to such issues as the use of resources and a changing climate. And therein lies the essence of the InterPlanetary Project itself: To use the whole galaxy and perhaps the whole universe as our kindergarten in becoming InterPlanetary Citizens with a decent record of stewardship of our own world that would make us worthy to visit (or be visited by) another world.

LARGE TEAMS DEVELOP; SMALL TEAMS DISRUPT

Modern trends in science and technology favor large teams of researchers, but we may be losing out on novel thinking in this movement away from small teams or individual research. In a study published February 15 in Nature, External Professor James Evans and co-authors analyzed more than 65 million papers, patents, and software products from the past six decades and discovered clear trends: large teams tend to draw on recent, popular research, building upon existing knowledge, while small teams are more likely to disrupt science by introducing new ideas. “Both small and large teams are essential to a flourishing ecology of science and technology,” write the authors.

COMPLEXITY EMERGES FROM SIMPLE NETWORK

In a new experiment in the “science of sync,” External Professors Raissa D’Souza, James Crutchfield, and their collaborators showed how complexity emerges from a toy network of nanoelectronic oscillators. Despite each network node being connected only to its immediate neighbor, the researchers observed nodes syncing with their neighbors’ neighbors — an emergent state. Their paper, published March 8 in Science, could eventually inspire technologies for intervening in heart arrhythmias or managing modern infrastructure.

ENERGY OVERSUPPLY UNDERLIES MULTIPLE CANCER RISK FACTORS

Obesity, diabetes, and chronic inflammation are well-established risk factors for cancer — but we may be losing out on novel thinking in this movement away from small teams or individual research. In a study published February 15 in Nature, External Professor James Evans and co-authors analyzed more than 65 million papers, patents, and software products from the past six decades and discovered clear trends: large teams tend to draw on recent, popular research, building upon existing knowledge, while small teams are more likely to disrupt science by introducing new ideas. “Both small and large teams are essential to a flourishing ecology of science and technology,” write the authors.

CHALLENGING THE FUNDAMENTAL ECONOMIC ASSUMPTION OF EQUILIBRIUM

One of the fundamental assumptions underlying most economic models is equilibrium — the idea that market forces tend toward a stable common point, and that people behave rationally. A paper published in Science, Advances on February 28 by External Professor Duncan Forster and co-authors suggests that this basic economic assumption may be an unrealistic one in many situations. Drawing from game theory and prior modeling on biological and social systems, the authors show that small teams tend to disrupt large teams by introducing new ideas like cell proliferation in check, but an energy overload can overwhelm those guardrails. The team used a computer model of cell evolution to simulate what happens to tissue during energy overload, offering a new explanation for how cancer evolves in many high-risk populations, and for why healthy diets and regular exercise can reduce cancer risk.

SCALE FREE NETWORKS ARE RARE

In research published in Nature Communications, External Professor Aaron Clauset and his co-author Anna Brodko from CU Boulder challenge a two-decade-old theory that many real-world networks are “scale-free,” and therefore follow a power law distribution. Drawing from a database of networks of various scientific domains, the researchers applied statistical tests to more than 900 networks, searching for evidence of scale-free architecture. About 4 percent of the networks studied passed the strongest test for being scale-free. Close to half of real-world networks did not meet a more liberal definition.

New books by SFI authors

The Human Network: How Your Social Position Determines Your Powers, Beliefs, and Behaviors (Pantheon, 2019) by SFI External Professor and Social Science Board member Matthew O. Jackson draws from psychology, behavioral economics, sociology, and business to take a complex systems-approach to understanding how human social networks, which hold a primary role in our daily lives, impact our personal beliefs and actions, and inform broader political and economic practices.

Emerging Syntheses in Science (SFI Press, 2019), edited by SFI co-founder David Pines re-enforces the debates and ground-breaking research that, in the syllogos, formed the foundation for the Santa Fe Institute.

First published in 1988, this new edition includes fresh essays by SFI President David Krakauer and Distinguished Shuman Professor Geoffrey West, the late David Pines, and Stephen Wolfram, a participant in the founding meetings. The volume also includes never-before-published transcripts from the founding meetings held in 1984.

LIFE FINDS A WAY: WHAT EVOLUTION TEACHES US ABOUT CREATIVITY (Basic Books, 2019) by SFI External Professor Andreas Wagner compares the tools of biological evolution with those of human innova-tion. He makes us see in the creative process happening in our minds all the time. Similar mechanisms underlie the processes of a musician rearranging musical phrases, a DNA strand coding multiple proteins, and a moth darkening over time. And as with genetic drift and DNA recombination, human creativity requires exploration and failure in order to find success.

RESEARCH NEWS BRIEFS

Above: Pierre and Marie Curie in the laboratory, circa 1904
2019 InterPlanetary Festival
June 14-16 at the Railyard Park in Santa Fe, New Mexico
The mission: To change the world, one planet at a time

SFI’s InterPlanetary Festival returns to Earth for three days of celebration and complexity science! Join luminary thinkers, creators, and scientists including celebrity physicist Sean Carroll, author and urban designer Nicholas de Monchaux, essayist Cyree Jarelle Johnson, chef and restaurateur Mark Miller, Nebula Award-winner Rebecca Roanhorse, and sci-fi novelists Daniel Abraham and Ty Franck, co-authors of “The Expanse” series under the pen name James S.A. Corey.

View complex challenges through an interplanetary lens in our provocative series of panel discussions — Building Life From Scratch, Creative Black Futures, Diverse Intelligences, Extremophile Cities, Time, and Vintage Space Technologies.


For an up-to-date lineup, and to register for this free event, visit interplanetaryfest.org

General admission is free to all, thanks to philanthropic support from:

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