Toward a new theory of birth, aging, and death

Few things occupy the public imagination like aging and death. But when it comes to organisms and systems beyond ourselves, there is still much we do not understand about either — even something as seemingly obvious as when something can be considered deceased.

“We know what we mean when we say a person is dead. This is because our concept of death is tightly connected to our own experience of life,” says Annette Baudisch, a demographer with the University of Southern Denmark. “Once we start discussing other types of individuals, it becomes tempting to mix up different kinds of death.” For a small planning meeting for a new working group, “The Birth and Death of Individuals,” which plans to develop a new interdisciplinary theory of birth, aging, and death, the group seeks to combine ideas from formal demography, scaling, and the theory of individuality. They have laid out four steps in forging the new theory: developing a framework for classifying individuals in time; crafting a typology of how individuals age, including individual societies and institutions; creating models to determine patterns of birth and death for those types; and analyzing how individuals within a population age. At the group’s planning meeting on November 24, Baudisch, Krakauer and a small number of researchers from a variety of fields began to tackle the first step.

“Before we talk about death we need to talk about individuals,” says Krakauer. “What is this unit that we describe as aging and dying?”

“The idea was that, once we have a kind of backbone general definition of ‘the individual’ in place, we can begin to put meat on the definition and distinguish among different types of individuals,” adds Baudisch. “Ideally we would like to identify a deep ordering principle along which we could align individual types.”

Doing so would lay the foundation for a general classification of death processes.

>> MORE ON PAGE 4

Searching for life as we don’t know it

Living things leave behind tell-tale signs of their existence: fossilized bones, DNA, the chemical byproducts of metabolism. Living things on Earth, that is. There currently exists no predictive theory to completely guide astrobiologists searching for life beyond our planet, where the chemical signatures of life, and the geo- and atmospheric chemistries under which it evolved, might look quite different from Earth.

In early November, NASA’s Astrobiology Program launched the new Interdisciplinary Consortia for Astrobiology Research (ICAR), supporting eight teams focusing on specific outstanding questions in astrobiology. SFI External Professor Sara Walker (Arizona State University) is leading one of the teams, an interdisciplinary group of theorists and experimentalists whose expertise in geochemistry, microbiology, exoplanet atmospheres, network theory, and complex systems will help them explore the question: What detectable universal patterns distinguish living chemistries across diverse planetary environments?

Answering this question, Walker says, will help astrobiologists develop a theoretical framework to refine their search for extraterrestrial life, and to be able to recognize life as we don’t know it. “So far, astrobiology has been really focused on the looking for chemistry of life as we know it — amino acids, metabolic byproducts like oxygen or methane,” says Walker. “What we’re trying to do is say that life is not a property of individual molecules; it’s a systems-level property that emerges from the interactions of many molecules and reactions. We want to understand and quantify the patterns in those molecules and reactions, then use those as new predictors of biosignatures.”

The team will build on SFI-related research on scaling laws and use techniques from complex systems science — tools that are fairly new in astrobiology. SFI Professor Chris Kemps, who is already leading a NASA Astrobiology Research Coordination Network has worked on identifying scaling laws and regularity in life on Earth, is part of Walker’s ICAR team. He hopes to uncover the observable universe. (Illustration: Pablo Carlos Budassi / Wikipedia)

>> MORE ON PAGE 4

An agenda for disinformation research

The use and spread of disinformation — false or misleading information intended to deceive people — is being amplified and accelerated at an alarming rate on the internet via social media. Within the U.S., this has quickly eroded trust in institutions that serve as the bedrocks of our society, such as science, the media, and government, to the point that we can’t even agree on basic facts.

In a white paper for the Computing Research Association’s (CRA) Computing Community Consortium (CCC), a group of researchers including SFI’s Joshua Garland and Elizabeth Bradley outline steps to begin dealing with the disinformation problem.

A key goal of disinformation is often to create confusion and dismantle trust in traditionally trustworthy organizations. One obvious example of disinformation today is the way COVID-19 has been called a “hoax,” which resulted in many people not viewing it as a real threat to their health or taking necessary precautions to prevent and contain its spread.

“Within the past few months, we’ve seen other large-scale disinformation about elections and the democratic process in terms of the validity, legality and security of mail-in ballots, fraudulent voting, rigged elections, dead people voting, supercomputers changing votes, etc.,” says Garland, an Applied Complexity Fellow at the Santa Fe Institute. “And there are many other examples surrounding migrants, vaccines, and climate change.”

Disinformation is an existential threat to democracy and society, points out Bradley, an SFI External Professor and a professor of computer science at the University of Colorado. “We technologists created many of the tools being used by disinformation creators and circulators — the internet, social media, etc. — and it’s incumbent upon us to think about solutions,” Bradley says.

One of CRA’s goals is to explore how computing research can help address national priorities. “Disinformation and the poisoned information environment we’ve all been swimming in needs to be a national priority,” says Nadya Bliss, executive director of the CRA’s Computing Community. The use and spread of disinformation — false or misleading information intended to deceive people — is being amplified and accelerated at an alarming rate on the internet via social media. Within the U.S., this has quickly eroded trust in institutions that serve as the bedrocks of our society, such as science, the media, and government, to the point that we can’t even agree on basic facts.

In a white paper for the Computing Research Association’s (CRA) Computing Community Consortium (CCC), a group of researchers including SFI’s Joshua Garland and Elizabeth Bradley outline steps to begin dealing with the disinformation problem.

A key goal of disinformation is often to create confusion and dismantle trust in traditionally trustworthy organizations. One obvious example of disinformation today is the way COVID-19 has been called a “hoax,” which resulted in many people not viewing it as a real threat to their health or taking necessary precautions to prevent and contain its spread.

“Within the past few months, we’ve seen other large-scale disinformation about elections and the democratic process in terms of the validity, legality and security of mail-in ballots, fraudulent voting, rigged elections, dead people voting, supercomputers changing votes, etc.,” says Garland, an Applied Complexity Fellow at the Santa Fe Institute. “And there are many other examples surrounding migrants, vaccines, and climate change.”

Disinformation is an existential threat to democracy and society, points out Bradley, an SFI External Professor and a professor of computer science at the University of Colorado. “We technologists created many of the tools being used by disinformation creators and circulators — the internet, social media, etc. — and it’s incumbent upon us to think about solutions,” Bradley says.

One of CRA’s goals is to explore how computing research can help address national priorities. “Disinformation and the poisoned information environment we’ve all been swimming in needs to be a national priority,” says Nadya Bliss, executive director of the CRA’s Computing Community.

>> MORE ON PAGE 4

>> MORE ON PAGE 4
This year more than a few of us sought solace. They have done so in different ways, reflecting the habits of the ascetic master — described the habits of the ascetic master, aesthetic, moral, and practical matters. For over a millennium chess and Go have been about patterns. But in Go the beginner has no choice but to script — somewhat like the end game of a DC superhero. In the Fortress of Solitude there’s an empty chair, willed not to leave it, but, abiding by the role of creativity in the science. Science breakthroughs. It was one of six selections for 2020. “This will always be remembered as the year the COVID pandemic,” said SFI’s deputy editor, John Rennie. “Grim as events have been, however, remarkable science has hardened on.” The SFI study, published March 24 in the journal Theory in Bioscience, uses information theory to answer one of biology’s biggest questions: what is an individual? The study was subsequently featured in a Quanta magazine article by staff writer Jordana Cepelewicz, and named in the magazine’s year-end review under “Biological Individuality and Symbiosis.” Instead of focusing on anatomical traits, like cell walls, study authors SFI President and William H. Miller Professor of Complex Systems David Krakauer, Nils Bertscherger (Frankfurt Institute for Advanced Studies), Eckhard Olbrich (Max Planck Institute for Mathematics in the Sciences), SFI Professor Jessica Flack, and SFI Professor Nihat Ay (also of the Max Planck Institute for Mathematics in the Sciences) look to structured information flows between a system and its environment. “Individuals,” they argue, “are best thought of in terms of dynamical processes and not as stationary objects.” Rather than a noun, they describe the individual as “a kind of verb.”

Jennifer Dunne reflects on a year without ‘superpowers’

In the Fortress of Solitude there’s a chair; in the clouds, there is Kryponian sun. There, the 1980 Superman lost his super-speed, super-strength, and ability — all the powers that defined him as a DC superhero. The Santa Fe Institute has always been defined by its ability to bring diverse thinkers into the same room to tackle important research questions. So for SFI, 2020 has been something like going into that chamber in the Fortress of Solitude. Jennifer Dunne, SFI Vice President for Science, jokes that the pandemic, with its necessary restrictions on in-person gatherings, “took away our superpower.” We recently spoke with Dunne about which aspects of SFI science can and cannot be replicated in a virtual environment, and what this means going into 2021.

Q: You’ve convened workshops and working groups to explore the role of creativity in the scientific process. How do online gatherings play into that process?

Dunne: SFI is very much about the creativity phase of science — the generation of new ideas and new collaborations. Given all the different ways of interacting deeply with people in-person and off-campus, that’s much harder to do virtually. On Zoom, due to latency and other issues, you can’t have opportunistic and easy-flowing conversations. The big drawback of online interactions is that you miss that serendipity of bumping into new as well as familiar people in the hallway or over lunch, tea, or coffee breaks. You miss going out to experiment — taking plants, animals, and atoms to speculate how others will vote. External Professor Henrik Olsson, who is a collaborator on the poll-project, was quoted in a Los Angeles Times feature about the efficacy of polling questions. External Professor Laurence Anzel Meyers and her team were recognized in a New Yorker feature titled “The Plague Year” for their early discovery of pre-symptomatic coronavirus transmission. Distinguished Shanman Professor Geoffrey West appeared on the French podcast ‘The Unravel to discover the heart of the climate issue. External Professor Ole Peters’ ergodicity approach to economics, which began with conversations at SFI during his postdoctoral fellowship, was featured in Bloomberg in an article titled ‘Everything We’ve Learned About Modern Economic Theory’. The Financial Times quoted External Professor Drayson Farmer in an article about a rising call amongst economists to measure a country’s economic health using contracts rather than GDP. (1)

CREDITS

Melanie Mitchell, SFI Davis Professor of Complexity, and External Professor Daniel Dennett contributed to a special New York Times review of “The Lasting Lessons of John Conway’s Game of Life.” An iconic example of emergence, the game produces diverse patterns from a few simple rules. In “Playing Go with Darwin,” a Nautilus op-ed, SFI President David Krakauer used Go as a metaphor for evolution — “game played across deep time.” The Washington Post, The Atlantic, and other outlets have credited SFI’s Harold Morowitz and his co-author Carl Sagan for first expounding on “Life in the clouds of Venus” in a 1967 paper. The work is gaining new attention after a recent, independent discovery of phosphine gas on Venus, which could indicate the presence of life (see p.2). Quanta magazine included SFI research on individuality in their year-end biology review (see below). In an op-ed for The Conversation, syndicated by Yahoo news and other outlets, SFI Professor Mitra Galeas and Wandi Bruno de Buen of UCB Dimesse described how to make election polls more accurate by using questions that ask participants to speculate how others will vote.

External Professor Henrik Olsson, who is a collaborator on the polling project, was quoted in a Los Angeles Times feature about the efficacy of polling questions. External Professor Laurence Anzel Meyers and her team were recognized in a New Yorker feature titled “The Plague Year” for their early discovery of pre-symptoms of coronavirus transmission. Distinguished Shanman Professor Geoffrey West appeared on the French podcast ‘The Unravel to discover the heart of the climate issue. External Professor Ole Peters’ ergodicity approach to economics, which began with conversations at SFI during his postdoctoral fellowship, was featured in Bloomberg in an article titled ‘Everything We’ve Learned About Modern Economic Theory’. The Financial Times quoted External Professor Drayson Farmer in an article about a rising call amongst economists to measure a country’s economic health using contracts rather than GDP. (1)

SFI IN THE MEDIA

Quanta magazine named SFI’s information theory in individuality in their year-end biology breakthroughs. It was one of six selections for 2020. “This will always be remembered as the year the COVID pandemic,” said SFI’s deputy editor, John Rennie. “Grim as events have been, however, remarkable science has hardened on.” The SFI study, published March 24 in the journal Theory in Bioscience, uses information theory to answer one of biology’s biggest questions: what is an individual? The study was subsequently featured in a Quanta magazine article by staff writer Jordana Cepelewicz, and named in the magazine’s year-end review under “Biological Individuality and Symbiosis.” Instead of focusing on anatomical traits, like cell walls, study authors SFI President and William H. Miller Professor of Complex Systems David Krakauer, Nils Bertscherger (Frankfurt Institute for Advanced Studies), Eckhard Olbrich (Max Planck Institute for Mathematics in the Sciences), SFI Professor Jessica Flack, and SFI Professor Nihat Ay (also of the Max Planck Institute for Mathematics in the Sciences) look to structured information flows between a system and its environment. “Individuals,” they argue, “are best thought of in terms of dynamical processes and not as stationary objects.” Rather than a noun, they describe the individual as “a kind of verb.”

Jennifer Dunne reflects on a year without ‘superpowers’
Music holds a unique power over our species. Exceptional care cases of what is called “musical anhedonia,” where a person’s brain scans show their auditory cortex isn’t linked to their reward circuitry, listening to music is like gambling or making love. So it is hard to imagine a more alluring topic for an SFI working group than “Complexity and the Structure of Music: Universals and Evolutionary Perspectives Across Cultures.”

Co-sponsored by SFI and the Institute for Advanced Studies Aix-Marseille University, France (IMRA), this forum brought together network and complexity scientists, musicologists, music theorists, composers, performers, and neuroscientists to trade ideas about the intersections of music and complexity from as many angles as possible.

“The abstraction of musical structures as geometrical spaces naturally invite the analysis of music as a complex system,” wrote the working group co-organizers in their meeting description. Co-organizer Miguel Fuentes is a complexity scientist and SFI External Professor, and co-organizer Marco Buongiorno Nardelli (University of North Texas, IMRA) is a composer, flutist, and computational materials physicist.

Meeting over three days, the international group rotated many conceptual objects of musical structure through myriad key and tempo changes, hosts, and other event-long side discussion in the Zoom chat. According to one participant, they were well aware of the meeting itself as an improvisational ensemble with learners seeking each other’s languages.

Ideas flowed at high speed as speakers shared their work: using network-based approaches to study composition and the evolution of forms over music history, identifying “rules” of music as emergent properties, acknowledging how the neuroscience of pleasure might encode in us a math and music that reflects our cultural constraints, and investigating how spaces shape the experience and production of music.

“Music is 35,000 years old at least, and we can use these amazing math and network tools to understand how humans think of music,” says SFI Complexity Fellow Stefani Crabtree, an archeologist and author who participated in the group. “How great is it to work with an interdisciplinary team?”

What is and is not universal stayed a central question through the talks. People teased at the prospects of applying complex datasets to music, or sifting through music-listening data to identify scale-free patterns in human attention, or using a network model for harmony to write generative algorithms for music both like and unlike anything we’ve ever heard.

On the last day the working group posed questions like, “How soon can we do this again?” and “What kind of fruit can an integrated mess of music lovers in the sciences make?” Stay tuned! [1]

NATURAL SELECTION PLAYS MAJOR ROLE IN AN ORGANISM’S CAPACITY TO EVOLVE

We know that natural selection shapes how animals and plants evolve and adapt. But does natural selection also influence an organism’s very capacity to evolve? And if so, to what degree?

A new study, published December 4 in Science, hints at some surprising answers to that question. A team of researchers led by External Professor Andreas Wagner (University of Zurich) subjected populations of a yellow fluorescent protein from a marine invertebrate to weak and strong selection pressures to find out which one enhances evolvability more effectively. The evolutionary end-goal was to get the protein populations to evolve from yellow fluorescence to green. The group under strong selection pressure won, because those populations underwent mutations that made them more robust — and therefore better able to evolve. “To our knowledge, this is the first experimental proof that selection can drive the ability to adapt in a Darwinian sense and increase evolvability,” says Wagner. He is hopeful that this will help settle the long-standing controversy over whether an organism’s evolvability itself can evolve.

Read the paper at doi.org/10.1126/science.abb5962

THERMODYNAMICS OF OUT-EQUILIBRIUM SYSTEMS

Arguably, almost all truly intriguing systems — stars, planetary systems, digital circuits — are far from equilibrium. But, until now, systems far from thermal equilibrium couldn’t be analyzed with conventional thermodynamics and statistical physics. In a paper published in the journal Physical Review Letters, SFI Professor David Wolfért presents a new hybrid formalism, weaving in nonequilibrium statistical physics and Bayesian networks to overcome all of the limitations of the earlier-developed, traditional fields. As an example of the power of this new formalism, Wolfért derived results showing the relationship between three quantities of interest in modeling nanoscopic systems like biological cells: the statistical precision of any arbitrarily defined current within the subsystem (such as the probabilities that the currents differ from their average values), the heat generated by running the overall Bayes net composed of those subsystems, and the graphical structure of that Bayes net.

Read the paper at doi.org/10.1103/PhysRevLett.125.200602

DIVERSITY BEGINS DIVERSITY

Most forms of life — species of mammals, birds, plants, reptiles, amphibians, etc. — are most diverse at the equator and least diverse at the poles. This distribution is called the latitudinal gradient of biodiversity.

Former SFI Postdoctoral Fellow Marcus Hamilton (University of Texas at San Antonio), Professor Chris Kumps, and their co-author were intrigued by the fact that human cultural diversity shows exactly the same distribution with latitude: human cultures are more diverse near the equator and least at the poles. To understand why, the group conducted a biogeographic and macroecological study of the distribution of mammal species diversity and human ethno-linguistic diversity around the world.

In their op-ed for Nautilus, SFI External Professor Melanie Moses (University of New Mexico) and her UNM colleague Kathy L. Powers, both members of the Interdisciplinary Working Group for Algorhythmic Justice, argue that the strategies scientists typically take to work with large-scale data often fail to address the grossly disproportionate effects of the pandemic on populations that face the highest risk. Moses and Powers argue that if scientists are to help public health policymakers meet their stated goal of protecting the most vulnerable, they must refine their methods to focus on the complex systems that govern communities that are most at risk.

MOSQUADES: Pandemic paths and the road ahead

One of the clearest messages to emerge from the science around the coronavirus pandemic is that science alone cannot contain a crisis. With this in mind, our faculty have been contributing to the public dialogue around the pandemic, sharing insights from complex systems through SFI’s own “Transmission” series and through op-eds in national news outlets. Here, we point to six prescient writings that made sense of the pandemic year and offer new insights for navigating the road ahead.

The complexity crisis

Nautilus

The COVID-19 pandemic can be understood as a complexity crisis in history, according to SFI Distinguished Shannan Professor Geoffrey West and SFI President David Krakauer. By recapitulating the kinds of challenges that are at the heart of such crises, complexity science can help us manage the pandemic’s long-term ramifications.

Complexity crises have two main features, according to West and Krakauer. First, they show the “failure of multiple coupled systems” — our physical bodies, cities, societies, economies, and ecosystems. Second, they call for solutions that involve unavoidable tradeoffs that amplifies initial system failures.

The COVID-19 pandemic has forced us to negotiate a tradeoff between social conventions of the pandemic; the new convention that helps us manage contagion. We choose between a handshake and elbow bump, for example. In general, it is necessary for us to move away from old conventions to retain new ones. Complexity scientists call the way that we lock in old habits “path dependence.” In the pandemic, path dependence suggests that trading olf habits for new ones is not a straightforward switch. Not only must we adopt new habits, we must also expend energy in breaking old ones. By illuminating the path dependence that characterizes the tradeoff between past and future conventions, complexity science can help us better manage contagion.

In their op-ed for Nautilus (also published in SFI’s “Transmission” series), Krakauer and West show that when we gain a clearer picture of the ways that different tradeoffs make us vulnerable, we can better atre up our interlaced systems.

Read more at nautilus.us/issue/88/risk/the-damage-were-not-attending-to

Misinformation is important public health data

STAT

The spread of the novel coronavirus has been a lesson for epidemiologists in the interplay between contagion of disease and contagion of misinformation. Until recently, however, many epidemiological models have failed to account for the ways that misinformation shapes the spread of disease.

In their op-ed for STAT, former SFI postdoc- toral fellow Laurent Hébert-Dufresne (Uni- versity of Vermont) and Vicky Chuqiao Yang, current Complexity Postdoctoral Fellow and Peters Hurst Scholar, argue that if scientists hope to develop better epidemiological models, they must grasp the complex interplay between social behavior and disease.

To illustrate their point, Hébert-Dufresne and Yang turn to data from the 2019 measles epi- demic that spread across the Philippines, wherein 40,000 people were infected and 500 died. As the authors explain, “the onset of the epidemic was largely driven by the spread of anti-vaccination sentiment, itself fueled by a dengue vaccine that failed to account for the interplay of dengue strains.” In short, the measles outbreak took part in the ways that helped shaped significantly by social behavior and public mis-information.

For Hébert-Dufresne and Yang, “social communi- cation and behaviors during an outbreak are just as important to public health as tests and diagnoses.” Scientists must seek data on these facets of epidemics if they are to model the complex path that epidemics take on the ground.

Read more at statnews.com/2020/04/07/ misinformation-outbreak-is-important-public-health-data/

Fear and the next epidemi- politico

For scientists who study the social dynamics that drive the COVID-19 pandemic, contagion is not a singular thing. As SFI External Profes- sor Joshua Epstein of New York University states, “For a disease like COVID-19, fear is as significant to the current pandemic as the novel coronavirus itself.” He observes that fear can both help and hinder public health responses to pandemics. In the 1918 influenza pandemic, for example, fear was helpful for reinforcing social distancing measures. When these measures were effective, fear about the pandemic allowed society to declare in fear that caused the second wave. On the other hand, scientists recognize that fear of both economic crisis and vaccination can worsen the problems they are trying to solve. For fear of economic collapse drives risky economic reopening; fear of vaccination can threaten our prospects for long-term public immunity. For Epstein, to formulate the strongest possi- ble public health response to the current pan- demic, political leaders must manage fear contagion on three fronts: disease spread, eco- nomic recovery, and vaccination.


Battle for the COVID-19 Narrative

Financial Times

COVID-19 is fundamentally changing the way we talk about the economy, writes SFI External Professor Wendy Carlín of University College London and SFI Professor Sam Bowles in an op-ed for the Financial Times. This presents oppor- tunities to develop language that fosters more humane economic policy. At other times in history, the authors point out, political leaders have redirected economic policy by reframing how we talk about eco- nomic life. Franklin D. Roosevelt, for example, shifted attention away from “hands-off, self-intered” to “freedom from want.”

At the moment, Carlín and Bowles write, “the battle to control the narrative is already underway.” Thought leaders have choices to make about what facets of human experi- ence they will emphasize in the economic vernacular of the near future. For Carlín and Bowles, the new narrative would do well to embrace three truths: first, that to be effec- tive, environments often depend on alliances that “trust public health and [are] commit- ted to rule of law.” Second, that political communities can and do act in strikingly civic-minded ways. And third, in contrast, segments of political communities can act in strikingly xenophobic ways. If we express these three truths — that alliances matter, Carlín and Bowles contend, we will be better equipped to respond to the kinds of crises that we can anticipate in our post-pandemic and climate futures.

Read more at www.ft.com/content/ cb827ca6-8a4d-11eb-b069-a9f0cfd1d6bf

Model for a just vaccination program

Nautilus

The COVID-19 pandemic has brought to light complex forms of racial injustice that are deeply entrenched in the American public health system.

In their op-ed for Nautilus, SFI External Pro- fessor Melanie Moses (University of New Mexico) and her UNM colleague Kathy L. Powers, both members of the Interdiscipli- nary Working Group for Algorhythmic Justice, argue that the strategies scientists typically take to work with large-scale data often fail to address the grossly disproportionate effects of the pandemic on populations that face the highest risk. Moses and Powers argue that if scientists are to help public health policymakers meet their stated goal of protecting the most vulnerable, they must refine their methods to focus on the complex systems that govern communities that are most at risk.

For Moses and Powers, the arrival of COVID-19 vaccines presents an opportunity to undertake this kind of analysis — and in so doing, address longstanding inequities. If we take a close look at how vulnerable populations are likely to access COVID vaccines, we can begin strategically to restructure systemic injustices in ways that will help rich communities become more resilient in the future.

Read more at nautilus.us/issue/93/for- forerunners-a-model-for-a-just-covid-vaccination-program

Uncertain times

Axon

For SFI Professor Jessica Flack and SFI Davis Professor Melanie Mitchell, the COVID-19 pan- demic prompts us to revisit the ways that complex systems retain stability in the biologi- cal world. By learning from biological systems, we can begin to see how systems are at the heart of economic crisis and contagion. One part of the system, say, social distancing poli- cies, reverberates in another part, say, stock market fluctuation, which reverberates in another part, say, governmental stimulus, and so on. Anyone looking at either the unfurling pandemic or the list of terms that characterize complex systems might wonder if we could detect clear patterns of stability in either place.

Yet as Flack and Mitchell illustrate, many complex biological systems help us see that nature regularly responds to destabilization with strategies that help life systems remain robust and adaptable. Schools of fish, when met with the threat of a shark, experience what scientists call a tipping point. The threat prompts the fish not into chaotic panic, as one might expect. Rather, it com- pels them to shift from shoaling, a weakly aligned formation, to school formation, which is highly aligned and allows the group more easily to evade the predator.

Understanding how biological systems respond to uncertainty and destabilization can help us discover strategies to engineer stability in our human complex systems — for the pandemic and beyond.

Read more at axon.co/essays/complex- systems-science-allows-us-to-see-new-paths-forward

First to forecast life above Venus

September 2020 brought a landmark discov- er for astrobiology — the discovery of a chemical compound in the clouds of Venus that is often associated with the presence of life. Though no SFI researchers were on the team that published the recent discovery of phosphine, one SFI scientist first forecast the possibility of Venusian life more than 50 years earlier.


“While the surface conditions of Venus make the hypothesis of life there implausi- ble, the clouds of Venus are a different story altogether,” wrote Morowitz and Sagan. “The discovery of phosphine — a chemical form of life that could survive by float- ing above the scorching surface of the planet, taking advantage of water, sunlight, and carbon dioxide which are prerequisites for photosynthesis. The 2002 discovery brought a new wave attention to Morowitz and Sagan’s article, with citations popping up in prominent science media outlets. (See [SFI in the Media, p.2])

Morowitz, who passed away in 2016, was instrumental in establishing SFI as a leading research center for biophysics and life origins. He convened the Institute’s inaugural workshop on the origins of life, a multi-institution, National Science Foundation-funded investigation that produced two leading, but incomplete, scientific expeditions.
InterPlanetary transmits new signal

SFI’s InterPlanetary Project has found a new way to celebrate the mutual influence of sci-fi and science.

In a podcast interview series that launched November 18, host Caitlin McShea, SFI’s InterPlanetary Project Director, and her guests explore the ways that science fiction and science can interact with each other. The series is based on the novel Roadside Picnic, by brothers Boris and Arkady Strugatsky, which imagines that an alien civilization visited our planet and left behind mysterious technologies at the landing site.

The story on the website reads:

Thirteen years ago, an alien civilization visited our planet, and left behind myriad, mysterious materials in their crash sites. These areas, Zones, behave very strangely, but the interplanetary items they contain could change the trajectory of our technological advancement. What appears as a slope might actually be a perpetuation machine. What appears as a slope might alter time-space. Spent too much time in the Zone and your genes might mutate, your body might be ground into meat. If you’re lucky enough to make it out alive, you’ll likely be imprisoned. But a successful trip in and out of the Zone could alter human history.

Do you dare? And for what?

As to why SFI, a scientific research institute, is discussing science fiction, SFI President David Krakauer, who conceived the podcast’s theme, says, “It’s because we believe that imagination should be unchained, and that, often, ideas of scientific value are derived outside of the rigorous scientific domain . . . the imagination and method together have superpowers.”

Alien Crash Site is SFI’s second active podcast, joining its official podcast, Complexity.

Catch the first four conversations at aliencrashsite.org, and subscribe to receive bi-weekly episodes at Apple, Spotify, or wherever you get your podcasts.

SFI’s first-ever virtual complexity program a success

It takes patience and plenty of goodwill to transform a dynamic and intense in-person summer program into a virtual experience that offers genuine and impactful connections. With the support of SFI Professor and Program Director Chris Kempes and Education Program Manager Carla Shedivy, ten students around the U.S. and international researchers mentored students over the Zoom task. This summer, in response to the ongoing coronavirus pandemic, SFI Education held its first-ever virtual Undergraduate Complexity Research (UCR) program.

“After some unplanned experiences with online classes in the months leading up to the SFI UCR program, my hopes were not very high for a virtual research experience,” says program participant Julia Beckwith. “I expected to be cordial with my peers, perhaps make some professional connections, and spend most of my time on Zoom daydreaming about the microscope in Santa Fe. I ended up making new friends, having great conversations with SFI professors and staff, and looking forward to our cohort’s ‘daily Zoom call.’”

Each summer, UCRs receive dedicated and expert mentorship on individual research projects, opportunities to meet SFI faculty, tutorials on how to conduct good research, and support and learning from one another. These experiences establish professional relationships that last far beyond the duration of the program. The virtual community created this year preserved theses important parts of the undergraduate program. The virtual community created this year preserved theses important parts of the undergraduate program.

“Something that’s new about the UCR experience is that students become equal members of the SFI research community,” says Kempes. “Rather than simply assisting with someone else’s work, we ask them to take full ownership of their project. They decide what they want to study and how to go about it with many researchers from SFI as collaborators. It goes far beyond computing and visualization. We’re creating the opportunity for in-person programming, SFI postdocs hosted two virtual game nights with the UCRs. Movie nights and other self-organized social activities made up opportunities for the UCRs to connect for fun as well as study.”

In 2020, the UCRs’ virtual constraints offered its own magic. “The summer was challenging but also exhilarating in ways that I never expected,” says Beckwith. “I loved jumping on Zoom to play online drawing games and talk about stand-up comedy and research dilemmas with my fellow UCRs before returning to edit an excessively long Python script.”

“Ultimately I learned that it really is possible to have your life changed over Zoom.”

“I usually don’t really appreciate the power of our ability to interact with others, but documenting and analyzing it, I realized that it was a really powerful tool to have during these times. So I learned to do that a lot more.”

“A UC meeting in 2020

SFI Professor Sidney Redner will receive the 2021 Leo P. Kadanoff Prize. The annual prize from the American Physical Society is one of its highest honors in theoretical physics.

SFI External Professor Tammy Bhattacharya of Los Alamos National Laboratory has been named a 2021 Laboratory Fellow. He is one of seven LANL scientists and engineers to receive this recognition for their scientific leadership.

AGING & DEATH (cont. from page 3)

At the group’s next meeting, the team plans to further refine the concept of the aging individ-
ual and identify and recruit researchers from additional disciplines who have studied differ-
ent types of death. In the meantime, Baudisch plans to begin work on a periodic table of sorts that lays out the organizing principles of life and death.

The researchers say the challenge of combating disinformation requires a comprehensive response that goes far beyond computing research, and includes education, psychology, economics, and other disciplines.

“There’s a tremendous need to understand how data-powered algorithms are impacting our reality and the offline world,” says co-author Chris Wiggins, an associate professor of applied mathemat-
ics at Columbia University’s School of Engi-
eering and Applied Science and the Chief Data Scientist at News Media Analytics. “Just like any other complex system, addressing this will require interacting with the system — here is the informa-
tion ecosystem — in a way that respects ethical concerns for rights, harms, and justice.”

“Our white paper outlines a clear agenda for research on the topic that could help inform a national response driven by the public and private sectors together,” says Biss.

LIFE (cont. from page 1)

As the team studies universal patterns on Earth, they plan to consider its biosphere as a multilayered environment, where the atmospheric, geochemi-
ical, and biochemical networks interact as a coupled system. The importance of this approach is highlighted by the recent phos-
phine-on-Venus debate,” says Kempes. “Phos-
phine was detected on Venus, and the question becomes: Is it a biosignature — for Venus? In general, it is likely to be a false positive or a false negative? To get at those questions, you need to understand the planet’s coupled net-
works and how different they might be with or without life in the loop.”

Walker adds, “If we are ever unambiguously to detect alien life, or even know how to properly look for it, we need quantitative frameworks. We need proper theory that allows us to know what life is. The tools to do that naturally come from complex systems research.”
The idea that you can choose to create beautiful scientific texts can surprise some people," says At SFI we are great admirers of the work of Turing and fellow codebreakers at Bletchley, as well as as for the mysterious symbols on the spine? These are the SFI Glyphs. We judge books by their covers, but also by their spines. These slim billboards teem with titles, Open the book, however, and we find that its origins are as contemporary as it gets: this is a brand-new volume from the Santa Fe Institute, home of complexity science. Academic publishing really attracts praise for aesthetics, affordability, or accessibility, but all three have defined the SFI Press since its founding in 2017. Supported by Bill Miller and the Miller Omega Pro- gram, it aims to bring new research from submission to publication within a year, at trade-book prices and in unique, collectible style. As for the mysterious symbols on the spine? These are the SFI Glyphs. "At SFI we are great admirers of the work of Turing and fellow codebreakers at Bletchley, as well as the doodle art of Henri Michaux, and the book notation systems of Walter Benjamin," says SFI Presi- dient David Krakauer, who also serves as the Press’s publisher and editor-in-chief and originated the series’ distinctive look. "In what shall remain a secret conversation [between SFI Press Manager Laura Egley Taylor and artist Brian Crandall Williams] combined with a series of stochastic permuta- tions with SFI staff, these influences and algorithms coalesced into the Glyphs."

On the shelf, Krakauer adds, those glyph-stamped spines give the impression of “an ancient artifact or ciphertext” while honoring the restrained tradition of Fitzcarraldo or Gallimard. So too does the cross-hatching of past and future circumscribe the books’ original artwork, from sand grains kalei- doscopied via macro-lens to the ambitious “photo-weavings” accompanying InterPlanetary Trans- missions: Standout, the proceedings of the second InterPlanetary Festival.

"The idea that you can choose to create beautiful scientific texts can surprise some people," says Egley Taylor. But then again, this is SFI, a place where a single conversation might range from Tur- ing’s codebreaking to the indiscernible sheen of a parakeet feather and back, and a designer is perfectly at home among physicists, computer scientists, and even a novelist or two. "There was no other way to do this." ©

The images used in the SFI-Press volume Worlds Hidden in Plain Sight (2018) were created using sand from SFI’s Cowan Campus. (Photo: SFI Press sfipress.org)

RESEARCH BRIEFS (continued from page 5) Their study, published in Scientific Reports, uses a novel sampling method to explore biodiver- sity. It finds parts of the planet that are diverse biologically and culturally are even more diverse than you’d expect. Read the paper at doi.org/10.1038/s41598-020-26658-z

THE RHYTHM OF CHANGE
Cultural practices evolve over time, influenced by widely studied psychological factors among individuals and, likely, by environmental factors like availability of materials or physical space. However, the effects of environmental influences have not been investigated experimentally, says SFI Complexity Postdoctoral Fellow Helena Miton. In a paper published in Proceedings of the Royal Society B, Miton and her collaborators studied how the rhythms changed through the transmis- sion. They hypothesized, correctly, that over time the rhythms would diverge significantly from the original seed rhythm, and in a specific way for each configuration. Read the paper at doi.org/10.1098/rspb.2020.2001

A NETWORK MODEL FOR IMPLICIT MEASURES OF ATTITUDES
Our attitudes are composed of an interacting constellation of feelings, beliefs, and behaviors, and these elements can be in conflict with each other. For instance, a person might believe in matic to our science’s Press’s publisher and editor-in-chief — the complex, self-contained subsystems that compose most of the universe. New research by SFI Professor David Wolpert published in the New Journal of Physics considers how a set of interacting subsystems affects the second law for that system. If you consider a thing as many interacting subsystems, Wolpert says you arrive at a “stronger version of the second law,” which has a nonzero lower bound for entropy production that results from the way the subsystems are connected. Read the paper at doi.org/10.1109/ICRA40945.2020.9196762

IMPLICIT BIAS ‘PERVASIVE’ WITHIN NEUROSCIENCE
In a Nature Reviews Neuroscience viewpoint piece published in September 2020, SFI External Professor Danielle S. Bassett (University of Pennsylvania) helped mark the 20th anniversary of the journal by sharing thoughts about remarkable neuroscience developments during the past two decades. Bassett and her coauthors point out that implicit bias within the field of neuroscience is perhaps more pervasive now — despite more diversity in terms of sex, gender, sexual orientation, race, ethnicity, and disability — because of the way it is embedded in research culture. Participants were divided into groups of six people. The first person listened to a particular rhythm. The second person listened to the first person’s attempt and tried to replicate it, and so on. Miton and her collaborators studied how the rhythms changed through the transmission of the rhythm. The second person listened to the first person’s attempt and tried to replicate it, and so on. Miton and her collaborators studied how the rhythms changed through the transmission of the rhythm. They hypothesized, correctly, that over time the rhythms would diverge significantly from the original seed rhythm, and in a specific way for each configuration. Read the paper at doi.org/10.1098/rspb.2020.2001

ENTROPY PRODUCTION GETS A SYSTEM UPDATE
The Second Law of Thermodynamics tells us that the average entropy of a closed system in contact with a heat bath — roughly speaking, its “disorder” — always increases over time. Puddles never refreeze back into the compact shape of an ice cube and eggs never unbreak themselves. But the Second Law doesn’t say anything about what happens if the closed system is instead composed of interacting subsystems — the complex, self-contained subsystems that compose most of the universe. New research by SFI Professor David Wolpert published in the New Journal of Physics considers how a set of interacting subsystems affects the second law for that system. If you consider a thing as many interacting subsystems, Wolpert says you arrive at a “stronger version of the second law,” which has a nonzero lower bound for entropy production that results from the way the subsystems are connected. Read the paper at doi.org/10.1038/s41598-020-26658-z

PREVENTING ECOSYSTEM TIPPING POINTS
To help prevent ecosystems on Earth from reaching their tipping points, SFI External Professor Ricardo Solé (Universitat Pompeu Fabra) and colleagues are turning to synthetic biology — with a twist on the old concept of terraforming or “Earth forming” on Mars to be used to save our own planet. In a Royal Society Open Science paper published in August 2020, they explore the concept of ecosystem terraformation, in which a synthetic organism is used to counterbalance some nonlinear effects causing the tipping points. “Many ecosystems may experience catastrophic decay within this century,” says Solé. “We need to explore new avenues to prevent it, and develop new interdisciplinary approaches and engineering strategies. We’ve been modifying the Earth by exploiting resources to build our civilization, but now our actions must help save the biosphere and ourselves.” Read the paper at doi.org/10.1109/ICRA40945.2020.9196762

METABOLIC SCALING THEORY FOR ROBOT SWARMS
A group of researchers recently designed a scalable architecture for a large swarm of robots to collect resources from an expansive area, such as the surface of Mars, and bring them back to a base station. In a paper published by IEEE in 2020, SFI External Professor Melanie Moses (University of New Mexico) and her students describe putting metabolic scaling theory to the test with swarms. In 1D, they found that a hierarchical branching network that mimics a cardiovascular network increases per-robot efficiency to 10-13 power of the swarm size, consistent with the theory. They also used the theory to predict the size of robot depots — essentially dump trucks — required to support a series of robot depots. Interestingly, the theory also predicts how swarms can produce scale-invariant foraging. “We show in simulations of thousands of robots, and a proof of concept with a real robot depot, that scaling theory provides a blueprint for an engineered network with near-perfect scaling,” says Moses. “Every robot is equally efficient no matter the size of the swarm.” Read the paper at doi.org/10.1109/ICRA40945.2020.9196762