Predicting steps in a random process

Tiny particles like pollen grains move constantly, pushed and pulled by environmental forces. To study this motion, physicists use a "random walk" model—a system in which every step is determined by a random process. Random walks are useful for studying everything from thermal diffusion to financial markets. But what if the environment itself—say, not just the walker—is random? "We can think of a town in which the elevation undulates in a random way, with the walker more likely to step downhill rather than uphill," says SFI Professor Sidney Redner. A fundamental question in this scenario, he says, is to determine the time for the system to move from one arbitrary point to another. This quantity is called the "first-passage time," and researchers have solved it in one dimension, albeit using cumbersome calculations.

In a paper published in Physical Review E, Redner, together with SFI Program Postdoctoral Fellow James Holehouse, introduced a new way to efficiently determine all possible first-passage times and their probabilities. Their approach, which relies on heady math, captures the randomness of both the walker and the environment. In the paper, they describe how to compute a "moment generating function"—a kind of mathematical machine for providing complete statistical information about the distribution of first-passage times.

Their approach could improve predictive analyses in a wide range of processes influenced by randomness, from changing biological populations to migration systems to the dynamics of financial instruments used to study markets. It builds on ideas that Redner first described in his 2001 book A Guide to First Passage Processes (for which he's preparing a second edition.) Researchers typically approach first-passage problems using enormous simulations, which start with initial systems and run through time to predict the time to reach a certain state. "But simulations are a really poor way to study these systems," Holehouse says.

Redner adds, "If you simulate some of these systems, you're guaranteed to get the wrong answer because you need to simulate so many instances of the system that to see the right answer would require a computation time that is beyond the age of the universe."
Beyond Borders

The city you live in could be making you, your family, and your friends more racist. Or, your city might make you less racist. It depends on how populous, diverse, and segregated your city is, according to a new study that brings together the math of cities with the psychology of how individuals develop unconscious racial biases.

The study, published in the latest issue of Nature Communications, presents data and a mathematical model of exposure and accumulation in social networks that can help explain why there is more unconscious, or implicit, racial bias in some cities than others. The authors hope that local communities and governments can use the findings to help create more just and equitable cities.

What I think is most interesting is the implication that there’s a piece of systemic racism that has to do with how people learn and the way cities are organized,” says psychologist Andrew Ster, an SFI Complexity Postdoctoral Fellow and lead author of the study.

Cities create dense networks of social interaction between people. Because of the interactions with literally different people, we need to be constantly adapting to new situations and learning.

But, once adopted into the production process, of machines, engines, designs, efficiency, etc., the consequences that have resulted from the use of tools and machines, engines, designs, efficiency, etc., are mechanical and intellectual organs, so that the workers themselves are cast merely as its conscious linkages.

Babbage conceived of his book as “one of the consequences that have resulted from the construction of the Difference Engine, the construction of which I have been so long superintending.” It was not Babbage’s intention to inspire a radical political economy, but to assess the most efficient means of manufacturing calculating engines.

“Of this much-abused Difference Engine is, however, like its predecessor the Analytical machine, a being of sensibility, of impulse, and of power”.

The insights of Babbage and Marx sound as relevant today as they were more than 200 years ago. Babbage was the first to see the potential of machines to supersede human work. Babbage made his name in 1832 with the publication of his manuscript called **Grundrisse**, or *The Economy of Manufactures*, which included extensive reflections on automation inspired by Babbage’s researches.

“Babbage conceived of his book as ‘one of the consequences that have resulted from the construction of the Difference Engine, the construction of which I have been so long superintending’. It was not Babbage’s intention to inspire a radical political economy, but to assess the most efficient means of manufacturing calculating engines.”

Scaling theory reveals patterns in urban waste production

Waste is a natural by-product of life on Earth and of productive human economies. Living systems have evolved to reconstitute waste — creatures like dung beetles fill an ecological niche of breaking down other organisms’ feces — but waste is a problem that still plagues human systems. As the world population continues to grow and rapidly urbanize — two-thirds of humans and of productive human economies. Living systems have evolved to reconstitute waste — creatures like dung beetles fill an ecological niche of breaking down other organisms’ feces — but waste is a problem that still plagues human systems.

The researchers took the average IAT bias scores from approximately 2.7 million individuals in different geographic areas and linked them to racial demographics and population data from the U.S. Census to build a model that accounts for how individuals learn biases through their social networks. They found that when these networks are larger, more diverse, and less segregated in cities, implicit racial biases decrease.

The results suggest that there are structural reasons why cities help or deter people from becoming less racially biased. Perhaps the most pronounced reason is the segmentation of different racial groups into different neighborhoods. Related to that is the lack of more cosmopolitan public spaces where a diverse range of people can experience positive interactions with one another.

In cities where people can’t encounter and interact with people and institutions used by other groups, racial biases create major barriers to equity. These barriers, the authors state, are associated with disparities across essentially all aspects of life including medical care, education, employment, policing, mental health outcomes, and physical health.

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Leah Magidson, Larry O’Hanlon, Stephen Ornes, Melissa Latham-Stevens

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Cities tend to deviate from the universal scaling law as they grow wealthier. Cities that are faster to categorize things when Black/good are paired they have a Black-good bias. "People may feel they are not prejudiced, but can unconsciously have a preference for one group or another," and this is revealed by these tests," Ster says.

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The resulting patterns show distinct differences in waste production as cities grow. Solid waste scales linearly — because it is tied to individual consumption, it increases at the same rate as population growth. In contrast, wastewater production scales superlinearly early while emissions scale sublinearly. In other words, bigger cities contribute disproportionally more liquid waste than smaller cities, but expel fewer greenhouse gasses. The results suggest an economy of scale for emissions as growth typically brings more efficient energy and transportation infrastructure, and a diseconomy for liquid waste.

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Dryland resilience

This semi-arid steppe in Compostela, Spain, displays the characteristic vegetative clusters found in drylands around the world. (Image: Miguel García-Gómez)

Many complex systems, from microbial communities to mussel beds to drylands, display striking self-organized clusters. According to theoretical models, these groupings play an important role in how an ecosystem works and its ability to respond to environmental changes. A new paper in PNAS focused on the spatial patterns found in drylands offers important empirical evidence validating the models.

Drylands make up 40 percent of the Earth’s landmass and are places where water is the limiting resource for life. They often display a characteristic clustering of vegetation surrounded by bare soil—patterns that are easy to spot in aerial images. The new study, led by SFI External Professor Sonia Kéfi (CNRS), finds that not only are these spatial patterns caused by the stressful environmental conditions of drylands, but they are also a critical adaptation that allows drylands to function in changing conditions. When a dryland ecosystem tips into a degraded state, the spatial patterns change.

“Many people have the idea that ‘interesting’ ecosystems are places like the Amazon, and that drylands are poor in some way,” says SFI External Professor Ricard Solé (Pompeu Fabra University), a co-author on the paper. “But they can be very rich. They are responsible for managing how water is being retained or not in these habitats, and are important for CO2 exchange.” Beyond their ecological importance, drylands are also home to one-third of the world’s human population, making them important economically and culturally.

In healthy dryland ecosystems, islands of vegetation create oases where conditions are a bit better than the rest of the landscape. There’s more water, more nutrients, and more shade. If an ecosystem’s climate becomes drier, those clusters tend to move further apart. And this, says Kéfi, is a double-edged sword. While improving local conditions, these clusters also create spaces without vegetation—harmful places where a single plant would not survive on its own. If conditions become too harsh, the ecosystem can reach a tipping point into desertification.

Kéfi and her colleagues wondered if aerial images, and their evidence of changes in spatial patterns, could themselves indicate the health or level of degradation in a given plot of land.

“In theory, we could tell something about the ecosystem from the sky—that’s what the models predict, in very broad terms,” says Kéfi. To test this, the team paired aerial images with soil and vegetation data gathered from 115 dryland ecosystems across 13 different countries. “This on-the-ground data shows us where one ecosystem is healthier or functioning better than other ecosystems.”

Using the two types of data, the team could test the predictions of the model against real-world observations.

“Our results represent a significant advance in the development of tools for the management and preservation of dryland ecosystems in a warmer, drier world,” says Kéfi. “More specifically, changes in spatial vegetation patterns (or the lack thereof) could be used as indicators of degradation.”

According to Solé, the study offers, for the first time, real validation that the model correctly predicts the non-linear dynamics of what has been unfolding in dryland ecosystems. The authors believe this will make it easier to spot degrading systems that might be approaching a tipping point. And, because vegetation patterns seem to also be key in other natural systems, such as microbial communities or coastal wetlands, their results could have implications for systems beyond arid zones.

Collectives are already known to behave differently from individuals...

TWO’S A COUPLE. THREE’S A COLLECTIVE.

According to the Gaia hypothesis, which was proposed by the scientists James Lovelock and Lynn Margulis in the 1970s, our planet should have been getting progressively warmer for millions of years, while our oceans should have been progressively more acidic as well. The fact that this hasn’t happened suggests a planet-wide complex system that is self-regulating, with planetary life and geological processes working together to stabilize planetary geology and climate. Despite its importance, this idea could not previously be tested due to its planetary scale.

In a recent paper, published in the Journal of the Royal Society Interface, SFI External Professor Ricard Solé (Pompeu Fabra), a co-author on the paper. “But it turns out that on the ground, this idea could not be tested due to its complexity. The planet’s complexity could not be tested due to its...”

Life as a planetary regulator

This semi-arid steppe in Compostela, Spain, displays the characteristic vegetative clusters found in drylands around the world. (Image: Miguel García-Gómez)

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Complexity tools for USDA nutritional guidelines

The decision of what to eat, and how those choices impact overall health, has always been complicated. Although nutritional guidelines can often offer guidance, there is no one-size-fits-all approach to a well-balanced diet, with factors ranging from a person’s health status, cultural background, and access to resources like farmer’s markets or well-stocked grocery stores, to personal dietary preferences.

“There’s enormous heterogeneity across people and across contexts,” says SFI External Professor Ross Hammond (Virginia Tech University-Brookings). “Making one-size-fits-all recommendations is difficult.” Given this complexity, nutrition is an ideal area to apply complexity science. In February, the U.S. Department of Agriculture released a commissioned report, which Hammond wrote with a team of other researchers, outlining specific ways that complex-systems science can be incorporated in shaping the country’s nutritional guidelines. The USDA’s Dietary Guidelines, updated every five years, offers advice on what individuals should eat and drink. But the impacts of these guidelines go well beyond the personal — they influence school lunches, federal food assistance programs, and the food industry more broadly. “The Dietary Guidelines are the central source for all evidence-based nutrition guidance developed by the federal government and shape hundreds of billions of dollars of annual federal spending,” says Hammond.

In the new report, Hammond and his coauthors outline six main strategies for incorporating complex-systems science into nutritional guidelines and offer a roadmap for creating a more nuanced, multifaceted approach to shaping nutritional policies. One strategy suggests including systems experts in the development of dietary guidelines, allowing new kinds of evidence and analytical tools to be included in the process. Another proposes using computational modeling tools from systems science to inform how diet guidelines are implemented; this process often includes a range of factors, including everything from our agricultural systems, vegetable chain issues, and environmental considerations. “That is a deeply complex-systems kind of question, because you are involving lots of different moving pieces,” Hammond says.

As Hammond notes, nutritional guidelines don’t exist within a vacuum, but rather are informed by a number of different social, cultural, and environmental factors. As a result, the number of Americans who follow the dietary guidelines is currently quite low, with the numbers remaining stagnant for decades. Systems science can offer insight into some of the main barriers that are preventing Americans from following dietary guidelines; offer more nuanced and flexible guidelines on diet to accommodate a wide swath of personal and cultural preferences; and identify potential strategies that can help Americans towards healthier eating patterns.

“Rather than a one-size-fits-all recommendation, what if we were able to have personalized recommendations that would suggest which are the things you could do right now, that would be easy for you, that would move you in the right direction?” Hammond asks. “What is the thing that you could do, that would really help?” Thanks to advances in systems science, we are getting closer to making this reality.

Second Complexity Global School to Launch in Colombia

This summer, SFI and the Universidad de los Andes (Unioandes) will host the second Complexity Global School. From July 21 through August 3, 60 students from Latin America, Western Europe, the Caribbean, the U.S., and Lebanon will gather in India and 30 African students remotely for several months after the in-person component concludes.

“One activity of reckless idea challenged us to break free from the constraints of our academic training and explore unconventional solutions,” says Sonya Kriyavasita, a student at Indian Institute of Technology, Delhi who attended CGS in 2023. “This experience helped me understand the importance of interdisciplinary collaboration in questioning dominant narratives.”

The quest for quantum gravity is to ask what time and space are. The main result, which took so long to develop, is that if you take general relativity, apply quantum mechanics, and calculate, what comes out is the uncertainty principle — there is no continuous space. This is a physical realization of macroscopic gravity, quantum gravity, a quantum theory of gravity that, unlike other theories of gravity, didn’t rely on a fixed background. They used loops, which are closed paths, to describe the behavior of gravity on a tiny scale. They gave talks in the U.S., Europe, and Asia that generated enormous interest, and Rovelli began writing his first papers.

Rovelli was finally being noticed. Back in Italy, universities now offered him a job, but he decided to join the University of Pittsburgh’s physics department. There, he worked with pioneers in general relativity, such as Ted Newman, and engaged in discussions with philosophers of science, such as John Earman. It was a decade before he returned to Europe and, together with Smolin, developed the ideas of loop quantum gravity into a fully formed theory.

“Studying quantum mechanics is about relationships, systems, structures, and orders that make the world,” says Rovelli. As in, meaning is created in relation to surroundings and is not inherent in individual things. He sees modern society as a machine that we perceive reality, and so he stays on course to question temporality, entropy, and the asymmetry of time in our universe. After all, who knows what the future holds?“

Colloquium: Updates from the SFI Press

Press works to visualize complexity

What does the emergence of a new paradigm look like? How might we visualize the history of complexity? Since beginning work on Foundational Papers in Complexity Science four years ago, editor David Krakauer and the SFI Press team have grappled with these questions. How, we’ve wondered, could we do justice to this overview of complexity and convey the experience of the books in a way that invites readers into this complex environment?

One answer is to turn to abstractions, graphic devices we can use to visualize the complex ideas of these books. A new project explores how to translate the narrative of the books, the way they tell a story and convey ideas, into visual representations.

The Press plans to start with two projects: one to produce an interactive visualization of the history of complexity, and a second one to create an online, two-dimensional visualization of the books themselves.

The history project is developing an overview of the history of complexity, including a timeline of key dates and people, and a visualization of the connections between those dates and people. The visualization is intended to be an interactive resource, allowing readers to explore the history of complexity in detail.

The second project aims to create an interactive visualization of the content of the books. This visualization will allow readers to explore the books in a new way, highlighting key concepts and ideas.

The Press is committed to creating a visual representation of complexity science that is both elegant, and unexpected, but also meaningful. The Press is also committed to making these visualizations available to the public, and to using them to engage new audiences with the rich and complex ideas of complexity science.
INTRODUCTION TO DIGITAL HUMANISM EXPLORES THE INTERCONNECTEDNESS OF AI AND HUMAN LIFE

In our rapidly digitizing world, humans have been handing over increased responsibility to AI and other digital tools — creating, writing and editing with Dall-E and ChatGPT, and asking algorithms to weigh in on important decisions like investing and financial loans. A new textbook co-edited by SFI External Professor Allison Stanger (Middlebury College) explores the implications of these decisions to make decisions for us and the best practices for integrating algorithms into our lives.

The free, open-source Introduction to Digital Humanism invites a human-centered approach to digital technology and weaves ethics, philosophy, and history into conversations about our modern age. In this multidisciplinary book of nearly 40 chapters, various authors delve into a wide range of digital advances and their consequences — both constructive and concerning — for humanity. For instance, one chapter explains the hidden labor involved in AI, involving countless underpaid and writing with Dall-E and ChatGPT, and asking algorithms to weigh in on important decisions like investing and financial loans. A new textbook co-edited by SFI External Professor Allison Stanger (Middlebury College) explores the implications of these decisions to make decisions for us and the best practices for integrating algorithms into our lives.

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The new gift will also cover the full cost of SFI’s Undergraduate Complexity Research program, which brings nine students to Santa Fe each summer for a 10-week immersive experience beside SFI mentors. Many UCR participants have gone on to pursue graduate degrees in areas they were introduced to at SFI, and often maintain research collaborations with other students and their SFI mentors.

And, the gift will supplement scholarships for many students enrolled in Complex Systems Summer School. The four-week intensive offers some 50 graduate students, postdoctoral fellows, and professionals the chance to transcend disciplinary boundaries, take intellectual risks, and ask big questions about complex systems.

“The McKinnon Family Foundation embeds a long-standing focus on education and New Mexico, so this gift to the Santa Fe Institute for complex-systems education and early-career research opportunities fits particularly well with that mission,” says Ian McKinnon. “One of the aspects of SFI which has always stood out to me is the way analytical rigor in its research approach is coupled with an appreciation for, and embrace of, the ineffable beauty of the complex adaptive systems which surround us. To the extent that this gift is targeted toward education and early career research, our hope is that we will help to empower new generations of complexity scholars who will apply that rigor and sense of beauty across a broad range of dimensions.”

The challenges that society faces today, from the future of work, to responding to novel pandemics, growing social and political polarization, and rapidly developing “intelligent” technologies are all rooted in complex adaptive networks. “Given that addressing some of the mostorny global challenges requires an approach rooted in complex-systems science,” says McKinnon, “we believe programs like the ones we are helping to fund will yield great returns for society in ways we can now only imagine.”

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RESEARCH NEWS BRIEFS

ANCIENT ROMAN PANDEMICS CONNECTED TO CLIMATE CHANGES
Recent climate changes have been linked to a lengthening laundry list of troubles, including famines, social turmoil, and disease outbreaks. Now the same sort of connections have been found between climate shifts and crises in the heartland of the ancient Roman Empire.

In a recent paper in Science Advances, SFI Fractal Faculty Kyle Harper (University of Oklahoma) and coauthors use plankton buried in millennia of marine sediments from the Gulf of Taranto (the arch in Italy’s boot) to track the air temperatures and precipitation from 200 BCE to 600 CE with a resolution of three years. It’s the first climate data from that period found so close to the center of the Empire. They found that colder periods after 100 CE are associated with records of pandemic diseases. The shifting climate caused the outbreaks in several ways, they explain, including changes in nutrition, conflicts over resources, and the varying populations of disease-carrying animals like mosquitoes and rodents.

Read the paper “Climate change, society, and pandemic disease in Roman Italy between 200 BCE and 600 CE” in Science Advances (January 26, 2024) at doi.org/10.1126/sciadv.adi033

DEFINING A CITY USING CELL-PHONE DATA
Humans are becoming more urban with more than half of the world’s population now living in cities. This rapid growth poses unique challenges to both the study and governance of cities — a challenge made harder because we lack a single common definition of “city.” Cities are often defined by political or administrative units or by built-up areas identified via satellite imagery. The best definitions depend on observing people’s mobility between home, work, and other activities — data traditionally collected via surveys, which are expensive, incomplete, and limited to a few nations. New technologies now offer a more complete picture.

In a recent Perspective in Nature Cities, SFI Professor Geoffrey West, External Professor Luís Bettencourt (University of Chicago), and co-authors propose that the geolocated data from the world’s more than 7 billion cell phone users could be used to map out city limits. Cell phone data accurately reveal people’s presence, movements and social interactions over space and time; these data are becoming the most widespread proxy for drawing city limits. Pairing cell phone data with other datasets, such as remote-sensing imagery and census data, could further improve accuracy and help advance the science of cities as complex systems and their role in global sustainability.

Read the paper “Defining a city — delineating urban areas using cell-phone data” in Nature Cities (January 11, 2024) at doi.org/10.1038/s44284-023-00019-z

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THE SANTA FE INSTITUTE COMMUNITY LECTURES
Being leading thinkers in Santa Fe to explore the most alluring questions in science, and to address the complex issues that face our species and our planet. All lectures are held at the Lensic Performing Arts Center.

THE LINEUP

TUESDAY, APRIL 4, 2023 @ 6:30PM
HENRY FARRELL & FRANCIS SPUFFORD

Tuesday, April 4, 2023 @ 6:30PM
Henry Farrell, Author
Comrades, Let’s Optimize! The Surprising Rebirth of the Planned Economy

TUESDAY, MAY 2, 2023 @ 6:30PM
DIANA REISS

Tuesday, April 4, 2023 @ 6:30PM
Diana Reiss
A Conversation with David Krakauer

TUESDAY, JUNE 6, 2023 @ 6:30PM
TINA ELIASSI-RAD

Tuesday, June 6, 2023 @ 6:30PM
Tina Eliassi-Rad
Making Sense of Chaos

TUESDAY, JULY 10, 2023 @ 6:30PM
BRANDON OGURUNU

Tuesday, July 10, 2023 @ 6:30PM
Brandon Ogurun
What is Life? Towards a Biology of Context & Complexity

TUESDAY, AUGUST 7, 2023 @ 6:30PM
DOYNE FARMER

Tuesday, August 7, 2023 @ 6:30PM
Doyne Farmer
Just Machine Learning

TUESDAY, SEPTEMBER 7, 2023 @ 6:30PM
ALISON GOPNIK

Tuesday, September 7, 2023 @ 6:30PM
Alison Gopnik
Animals in Translation: What WILL Take to Make an AI Smart as a 2 Year Old?

TUESDAY, OCTOBER 2, 2023 @ 6:30PM
KYLIE HARPERS

Tuesday, October 2, 2023 @ 6:30PM
Kylie Harper
University of Oklahoma, SFI Fractal Faculty
Climate Change and Extinction: Complex Crises Past and Present

This year’s Community Lecture Series began on April 4 with a talk by Henry Farrell and Francis Spufford. Reserve free tickets for upcoming talks to join us in person at the Lensic Performing Arts Center in Santa Fe, or follow the livestreams online. More details at www.santafe.edu/community.