Bill Miller gives $50 million to SFI

In the largest single donation in its history, the nonprofit Santa Fe Institute will receive $50 million from legendary investor Bill Miller. The gift will advance the Institute’s pioneering science of complex systems by growing its research community and expanding the facilities in which it works.

Complexity science seeks to find the organizing patterns at the heart of systems with a multitude of adaptive parts — from economics to ecosystems. Many scientists, including the late physicist Stephen Hawking, predicted that the 21st century would be "the century of complexity," when science would build on the foundational laws of physics by understanding "how the laws fit together, and what happens in extreme circumstances," Hawking said.

"This gift comes at a moment when the world needs radically new ideas and quantitative frameworks to engage with the growing connectedness and complexity of life and the accelerating pace of change in both technology and society," says SFI President David Krakauer.

"Bill’s gift supports the search for new foundational ideas bearing on our understanding of complex reality, which includes consideration of the planetary future, our increasingly hybrid nature with machines, and potential existential issues around climate, our democracy, and rationality."

Beyond being the largest single donation in SFI’s history, Miller’s gift is also believed to be the largest gift explicitly dedicated to support the science of complex systems, which is also called "complexity." The Santa Fe Institute is the only stand-alone institute in the world dedicated to advancing the frontiers of this field.

Ecologist Jennifer Dunne, who is SFI’s Vice President for Science, remarks that "Bill’s gift to SFI is extraordinary and provides us with the means to expand and sustain important research and outstanding researchers in complexity science for many years to come. It demonstrates how he fundamentally resonates with the Santa Fe Institute’s quest to bring the most diverse, brilliant, and curious minds together (including his!), to make progress on the most interesting and difficult questions facing our world.”

For scientists at SFI, the gift marks a turning point in the mainstream establishment of complex systems science, in the same year the

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SFI applauds first Nobel Prize for complex systems research

SFI researchers cheered this October when the Nobel Prize in Physics was awarded to Syukuro Manabe, Klaus Hasselmann, and Giorgio Parisi "for groundbreaking contributions to our understanding of complex systems."

Spanning disciplines and notoriously difficult to define, complex systems science has struggled to achieve the mainstream recognition of older, more established fields. But the acknowledgment from the Nobel Committee, arguably the most prestigious award-granting assembly in the world, has emphasized its importance and beauty.

Professor Jessica Flack hailed the decision as "surprising and entirely overdue" in a Twitter thread that details the deep implications of Parisi’s work in social and biological sciences, from starling flocks to neuroscience to the concept of renormalization in particle physics. Though a physicist by trade, Parisi’s work modeling spin glasses — a kind of disordered magnet — turned out to be applicable to a variety of other fields where understanding disorder is critical.

"Great news today with the @NobelPrize to legendary Italian physicist Giorgio Parisi," tweeted SFI External Professor Ricard Sole. "His work has a major impact in biology, from molecular evolution to neural networks and the dynamics of complex adaptive systems. Very much deserved."

The study of complex systems, to Parisi, was nothing short of a revolution in physics: "[T]he necessity to change the general philosophy, by introducing probabilistic concepts and probabilistic predictions," he wrote in 2002. Over the past few centuries, physicists have dismantled the order of Newtonian mechanics, revealing a world that can only be

> MORE ON PAGE 4

Emergent engineering for an evolving world

When Alexis de Tocqueville observed American democracy for the first time, he was so astonished at what he saw that he made a proclamation: “a new political science is needed for a world altogether new.” Tocqueville had been born a twenty-first-century technological visionary, perhaps he would have said something slightly different — something like this: a new kind of engineering is needed for a world altogether new.

Over the past three years, SFI’s Applied Complexity Network (ACiOn) has had a front-row seat in a series of meetings where SFI researchers have been evolving this new kind of engineering, one better suited to the complex systems that drive the contemporary world.

Called emergent engineering, it generates the conceptual frameworks and design principles that practitioners need to carry out engineering projects that engage with adaptive agents.

The inaugural exploratory meeting took place in June of 2019, followed by a virtual roundtable in September 2020, and, later that year, a series of roundtables that homed in on emergent engineering in the organization, and in the market, respectively. To continue developing the theme, in November 2021, SFI hosted a virtual ACiOn Board of Trustees Symposium dedicated exclusively to the subject.

One way to understand emergent engineering is by comparison to classical engineering. Whereas classical engineering works with systems that exhibit (more or less) deterministic patterns (think: the steam engine, Newtonian mechanics, or even a supply chain), emergent engineering engages with agents and systems that evolve and adapt (think: ecosystems, public health care, and cybersecurity).

For SFI President David Krakauer, an illuminating example of emergent engineering is the cochlear implant. As Krakauer explains, "the cochlear implant stimulates neurons directly, and essentially simulates the tonotopic frequencies. The designer of a cochlear implant, therefore, has to
**BEYOND BORDERS**

The pursuit of the most parsimonious model

The Kermack and McKendrick paper introduced the idea of the basic reproductive number $R_0$, which is a measure of the average number of secondary cases of infection produced by a single infected individual in a completely susceptible population. This concept is central to understanding the spread of infectious diseases and has been a cornerstone of epidemiology.

According to the second law of thermodynamics, the total entropy of a closed system can increase or stay the same but never decrease. When a system evolves over time, the entropy either increases or remains constant. This principle is known as the second law of thermodynamics.

In dynamical systems research, a “basin of attraction” is the set of initial conditions that lead to a particular attractor or fixed point. The basin of attraction tells us where a system ends up. Some systems are easy to compute numerically, while others can be high-dimensional and challenging to analyze.

The work may also have real-world implications. Zhang points to the early age of exploration for basins. "This is not something that so much is known," says Strogatz. "This is not something that so much is to remind people that so much is waiting to be found. This is the early age of exploration for basins."
Some colleges are mammals, others are cities

Higher education in the United States spans five orders of magnitude, from the tiny institutions like the 26,000-person Deep Spring College in the high desert of eastern California to behemoths, like Arizona State University, a city the size of Cleveland.

“Community colleges, in particular, are much more like organisms,” says West. “They emphasize efficiency, and they deliver on that and they’re mean and lean, and big universities are rich and fat and getting fatter.”

The largest community colleges spent less than half as much per student as the smallest ones did. On the other hand, as prestigious research universities grew in size, tuition and faculty salaries increased, while research productivity and quality substantially increased. Kemps, who co-led the project with former SFI Postdoctoral Fellow Marion Dumas, noted that this superlinear growth “everything is getting better, better, faster” was similar to the way cities follow scaling laws.

“Community colleges, in particular, are much more like organisms,” says West. “They emphasize efficiency, and they deliver on that and they’re mean and lean, and big universities are rich and fat and getting fatter.”

Critically, this efficiency doesn’t seem to come at a cost to completion rates — by that measure students are still graduating at the same rate, even though they’re saving money. Using data from mid-career salaries of graduates from 1984 to 2014, the researchers were also able to compare the return on investment for institutions. Again, community colleges punched above their weight, with more expensive schools earning their tuition growth compared with graduate salaries as schools become larger.

Why exactly institutions of higher education follow the trends they do is still not clear. One mechanism, West says, is that institutions are trying to optimize education and research. Some schools also choose specifically to stay at a certain size. In future work, Kemps hopes to separate a genuine scaling effect of size and category from a strategy.

While the current paper does not address policy implications, the authors note that it suggests institutions success should be measured relative to scale. An institution that seems to underperform might in fact be overperforming for its size — not unlike a mammal, or a city.  

When does reputation lie?

Consider two stories, the first, about a boy who gets all the attention. His classmates graduate and end up in classes who come from a well-known family. He seems to soar through life. When he gets few to see. The more popular he is, the more beloved he becomes. The second girl who can’t thrive. She tries and tries, but she has few friends. The more she is shunned, the more discouraged she becomes.

Does the boy merit his standing? Or does his status ensure his success? Is the girl trapped in a system that holds her down? Or does his status ensure his success? Is the girl trapped in a system that holds her down? Or does his status ensure his success? Is the girl trapped in a system that holds her down? Or does his status ensure his success? Is the girl trapped in a system that holds her down? Or does his status ensure his success? Is the girl trapped in a system that holds her down?

These are questions explored in a new paper that grew from hallway conversations among former SFI Postdoctoral Fellows Eleanor Power and Marion Dumas (both of the London School of Economics and Political Sciences) and their colleagues Jessica Barker (Aarhus University and the Alaska Department of Health and Social Services).

The researchers developed a theoretical framework to assess the interplay of reputation, social prominence, and social capital. The research draws from Power’s ethnographic work among South Indians who perform intense acts of religious devotion such as firewalking and body piercing in gratitude toward a Hindu goddess.

Power recognized that religious participation is tied to status and the strength of one’s social support networks. More devoutly you behave, the greater your reputation. But not all is equal — some low-status villagers — particularly women and Dalits — don’t get the same benefits from their actions. And their mistakes — say, tripping over hot coals — can be seen as divine interventions from a single volume. Sheldrake invites his readers to question not just perception but consummation, and to feel the complicated possibility of velvet.

SEAN CARROLL, Research Professor of Theoretical Physics at the California Institute of Technology and SFI Fractal Faculty and External Professor

What we’re reading

Books chosen by SFI scholars on the theme of ‘Deception’

Despite the obvious human yearning for truth, we also appear to have an equivalent yearning for deception. As Friedrich Nietzsche succinctly put it in Beyond Good and Evil, “Whatever is profound loves masks.”

The pleasures and benefits of deception are apparent in almost every era and in all sorts of social and commercial endeavors, from the theater, the arts, and Plato’s “noble lie,” to mass media, camouflage, and cosmetics, and so on. Deception, used in the right circumstances, can be a force for social cohesion, good governance, and stability. But it may also have pernicious, even existential, consequences.

“Drive Your Plow Over the Bones of the Dead” (Penguin Random House, 2019) by Olga Tokarczuk, translated by Antonia Lloyd-Jones

“In perception velvet or gauzy? Without having felt perception fray, without experiencing the vertigo that comes with the labyrinth dissolving, to ask this question is purely an intellectual exercise. Tokarczuk’s Janina — translator of William Blake, guardian of forest animals, and a person in love with the world — is a ‘sea breeze, a summer night star’ — compels her readers to question not just perception but consummation, and to feel the complicated possibility of velvet.

ANDREA WULF, Author of The Invention of Nature and SFI’s Miller Scholar

“Dr. Coppeleder’s History of Magic” (Simon & Schuster, 2021) by David Coppeleder, Richard Wiseman, and David Britland

David Coppeleder has assembled a unique museum devoted to the history of magic, from the 16th century through Houdini to today. But the collection isn’t public — can’t give away the secrets! Instead, we have this new book, a sumptuous illustrated tour of the most important milestones in the history of illusion.

JESSICA FLACK, SFI Resident Professor and Cq Director

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College of DuPage, in DuPage, Illinois (Photo: Jimmy Tompkins/Unsplash)
In this elegantly designed book—a tome of varied perspectives on the wide-ranging impacts of the COVID-19 pandemic—researchers from across the sciences weigh in on topics ranging from modeling transmission to decision-making in the face of uncertainty, to how wildlife responded to suddenly empty landscapes. This collection of articles, written for a general audience, underscores the importance of resisting simple answers in combating a phenomenon as complex as a global pandemic and instead recognizing its multidimensional nature. Much of what went wrong during the pandemic can be attributed to overly simple, one-size-fits-all solutions,“ write the editors of the Special Issue, SFI President and William H. Miller Professor of Complex Systems.

David Krakauer and Shannan Distinguished Professor and Past President Geoffroy West write in the introduction. While there can be great comfort in embracing simplicity, “there can also be a certain naiveté in the excessive elegance that sometimes accompanies simplicity. And of greater concern is the danger in the desire for explanation—to explain every event or phenomenon as if it had a single cause and to flatten and linearize natural processes as if our future is as predictable as its past is comprehensible.” The book, they add, “disavows simple explanations and solutions in favor of a concerted effort to come to terms with the whole matrix of the pandemic and all its messy parts.” As we struggle to grasp the full magnitude of the damage the pandemic has wrought and challenges Complex Alternative offers a wealth of nuanced insights into what we’ve learned—and makes an important contribution to the conversation about what we must do to better prepare for the next one.

Miller credits his 30-year involvement with SFI for inspiring four major decisions in his investment career which significantly contributed to his fortune. But for Miller, the new gift to SFI isn’t about repayment or monetary investment—it’s ‘a personal investment in the future of humanity.’

“My long affiliation with SFI has been among the most rewarding of my life, both personally and professionally,” says Miller. “SFI scientists have been among the most exciting and important scientific problems that we face. I am delighted to be able to contribute to the critically important work that is being done.”

Miller, whose formal name is William H. Miller Jr., first visited SFI in 1991 and joined its board in 1995. He has since served SFI as Chair; Vice-Chair; and Chair Emeritus of the Board of Trustees. He is currently the founder of investment firm Miller Value Partners. He spent 35 years at global investment firm Legg Mason.

Bill Miller (courtesy photo)
The challenges society will face in the coming decades will require cooperation, but trends toward partisanism, populism, and polarization around the globe could impact our ability to work together to meet those challenges. In a special feature in the Proceedings of the National Academy of Sciences, researchers from various fields explore these trends as systems-level phenomena. “In viewing political systems as complex adaptive systems, we can gain a new understanding of the forces that shape current trends, and how that knowledge might affect governance strategies going forward,” writes SFI’s Simon Levin with special feature co-editors Helen V. Milner and Charles Perrings in their introduction. “Extreme polarization is a dangerous phenomenon that requires greater scientific attention to address effectively.”

The 11 papers and additional perspectives in the special issue include contributions by SFI’s Stephanie Forrest, Jenna Bednar, and Scott Page, and came out of a series of “Dialogues in Complexity” workshops co-hosted by Forrest and Levin with Andrea Graham and Ann Kinzig. The articles represent collaborative research between political scientists and complex-systems theorists. “Polarization is a process and that is what complexity theory can best help us understand,” write Levin, Milner, and Perrings. “The main goal of the Special Feature is to deepen our understanding of the dynamics of political polarization and related trends, and especially the interplay among these processes at multiple scales, from the local to the international.”

Affiliations and Funding: Andrea Graham (Princeton University); Ann Kinzig (Arizona State University); Simon Levin (Princeton University); Helen V. Milner (University of Michigan); Scott Page and Charles Perrings (Arizona State University). Dialogues in Complexity workshops supported by funding through Arizona State University.

Understanding the emergence and perils of polarization

We can’t understand polarization unless we analyze it as a complex system, argue SFI External Professor Scott Page (University of Michigan) and co-author Delia Baldassarri (New York University) in a commentary for the special feature in PNAS. Polarization occurs both in ideology (beliefs about the world and appropriate policies) and emotion (disrupt or disconnection between the groups), and it is the feedback loops between these two types of polarization that make it such a difficult problem to solve. Positive feedback loops — where divergence creates more divergence — build polarization in the first place; negative feedback loops stifle attempts to build bridges across groups.

Different models of polarization highlighted in the special feature shed light on particular aspects driving it. One model assumes that people become more like those who agree and diverge from those who disagree. That simple force transforms an ordinary array of varying opinions into two camps. A second model highlights the role that technology plays in enabling this movement, making it easier to link with those with similar views and to avoid those who disagree. And a third views polarization as a result of the overwhelming complexity and multidimensionality of the issues voters face: incapable of deciding issue by issue, citizens look to elites and political leaders to simplify, and party leaders have incentives to build loyal, ideologically clustered networks of supporters.

Getting out of our polarized state, which according to some models will demand more effort than was required to get into it, will hinge on a deep understanding of the multiple forces that got us where we are now. The different theoretical explanations these models provide offer a start on that.

Preventing extreme polarization of political attitudes

Encouraging interactions between people on opposite ends of the political spectrum may not be the best way to foster tolerance in a polarized nation. In fact, a new study in the PNAS special feature suggests extreme polarization can be avoided when two sides of a stubbornly intolerant population have low exposure to each other.

SFI External Professor Stephanie Forrest; a computer scientist (Arizona State University), and coauthor Joshua Daymude, a postdoctoral researcher (Arizona State University), and Robert Axelrod, a professor of political science (University of Michigan), created an agent-based model to study ideological polarization that is unique in its simplicity. In their Attraction–Repulsion Model (ARM), each individual is assigned two rules governing their behavior. In essence, the rules dictate that individuals move closer to or further away from extreme positions based on their attraction or repulsion to others’ ideological positions.

“We tried to make the simplest model possible that captures what we thought were realistic assumptions,” Daymude said. “It enables us to ask questions like what happens over time when the agents are more or less tolerant of others’ ideological positions or more or less likely to be exposed to differing viewpoints.”

Using the model, the researchers showed that a high level of intolerance was the key component of runaway polarization, especially when it was enhanced by high exposure between dissimilar individuals. “While it at first may appear contrary to practical experience, our model suggests strictly limiting exposure to dissimilar views could be an effective mechanism for avoiding rapid polarization,” Daymude said.

Another interesting finding of the study was that extreme polarization could be avoided when individuals were assigned a preferred ideological position based on economic self-interest and acted in favor of this assigned position. “Even a small amount of self-interest can dramatically reduce polarization,” Forrest said. “This is perhaps the most promising result of the model because it suggests a direction for policy intervention by which the polarizing dynamic could be moderated.”

Polarization occurs both in ideology . . . and emotion . . . and it is the feedback loops between these two types of polarization that make it such a difficult problem to solve.

Polarization, diversity, and democratic robustness

Polarization is dangerous for democracy. Though the U.S. Constitution was designed to harness rivalry with a diverse, redundant, and modular set of institutions, if that rivalry curdles into the belief that your competitors are your enemies, those institutions may not be strong enough to hold a nation together.

In a Perspective piece in the PNAS special feature, SFI External Professor Jenna Bednar (University of Michigan) argues that polarization poses three perils in particular. The first problem is that people tend to gather with those who think similarly and avoid those who think differently, accentuating a dictate for those who differ. Second, elites can manipulate the public through fear, persuading their followers that others pose an existential threat — and then that fear can feed on itself, beyond all control. And third — and most dangerous, Bednar argues — is that the positions of the population become simplified, with less room for individual variation in beliefs. This can happen, for example, when each group polices the beliefs of its members and punishes those who don’t conform with the established party line. This creates a loss of diversity in opinions that imperils democracy just as species diversity loss imperils ecosystems.

PNAS Special Feature

A look at the dynamics of political polarization

Northampton, MA. USA 5/2/2020 Pro trump supporters rally in Northampton MA to protest corona virus lockdown. (Photo: Shutterstock)

IRVING, TEXAS, USA-MAR 2, 2018: Yard sign at residential street near library for primary election day in Dallas county. (Photo: Shutterstock)

Washington, D.C., USA. 24 March 2018. Thousands of students and supporters gather along Pennsylvania Avenue to rally against and protest school gun violence. (Photo: Shutterstock)

Washington, D.C., USA. 24 March 2018. Thousands of students and supporters gather along Pennsylvania Avenue to rally against and protest school gun violence. (Photo: Shutterstock)
“Solutions” presents citizens and societal decision-makers with what SFI External Professor Steen Rasmussen calls “a laundry list” of takeaways that highlight the power of complex-systems thinking to address the challenges of the 21st century.

“Solutions” brings viewers into the room with complexity scientists, offering the opportunity to experience conversations that highlight the power of complex-systems thinking to address the challenges of the 21st century.

Developing new theories for understanding what life is, and identifying universal laws of life that could apply to life throughout the universe.

External Professor Jean Carlson (UC Santa Barbara) was named a fellow of the American Physical Society, acknowledged “for the development of mathematically rigorous, physics-based models of nonlinear and complex systems that have significantly impacted a broad range of fields including neuroscience, environmental science, and geophysics.”

COMPLEXITY’S POWER (cont. from page 3)

“Solutions” brings viewers into the room with complexity scientists, offering the opportunity to experience conversations that highlight the power of complex-systems thinking to address the challenges of the 21st century.

We all believe we want to change the world,” says participant Doyne Farmer, an economist and SFI External Professor. “It’s not just an empty academic exercise.”

Directed by award-winning filmmaker Pernille Rose Grønklit, “Solutions,” was selected for UNAFF by a 24-member jury for its relevance and potential to capture audiences. The documentary has already been lauded as a “music see” in academic circles and won the Grand Prize at the 2021 Prague Science Film Festival. It has also been accepted to film festivals in Australia, Norway, and Russia, and is in the running for several more awards.

INFORMATIONAL ARCHITECTURE ACROSS NON-LIVING & LIVING COLLECTIVES

The intensifying search for life on other worlds begs an important question: Will we recognize life when we find it? A living thing on another planet may look quite different than any alien lifeforms we know — characteristics such as how collective behaviors are exhibited in each system. New work co-authored by SFI External Professor Sara Imari Walker and colleagues developed an innovative way to determine the differences in collective behaviors between living and non-living systems: comparing their information architecture, or how information is stored and processed. The paper, published in a special issue of Theory in Biosciences on quantifying complexity edited by SFI’s Jessica Flack and Manfred Laubichler, aims to help improve the way collective behaviors are quantified — and leave us better prepared to recognize life on other planets, if and when we find it.

Read the paper at doi.org/10.1007/s12064-020-00331-5

INNOVATIONS ARE DISPROPORTIONATELY LIKELY IN THE PERIPHERY OF A SCIENTIFIC NETWORK

The advancements of everything from science to education relies in large part on the ability to come up with new ideas. But under what conditions is innovation most likely? To help answer this key question in the science realm, SFI External Professor Manfred Laubichler and colleagues developed a framework to identify the origins of innovation across one field: evolutionary medicine. They conducted an automated analysis of more than 6,000 documents, including every paper in the field published before January 2018, measuring the novelty and acceptance of the ideas. The team then determined whether they fit within well-established lines of inquiry or fell on the periphery. The authors found that most innovations occurred at the fringe — suggesting that skirting the status quo “could be beneficial to creating novel and lasting change.” The analysis was published in a November special issue of Theory in Biosciences on quantifying complexity, edited by Laubichler and SFI Resident Professor Jessica Flack.

Read the paper at doi.org/10.1007/s12064-020-00335-1

SLOWED CANONICAL PROGRESS IN LARGE FIELDS OF SCIENCE

In recent years, many academic disciplines have seen steady growth in the number of papers published as the fields aim for more researchers, funding, and output. But more papers don’t necessarily mean a commensurate expansion of ideas. In fact, as SFI External Professor James A. Evans and co-author Johan S. C. Chu propose in a recent study in PNAS, too many papers can lead to stagnation rather than advance. The authors examined 7.8 billion citations referenced in 90 million papers across 241 fields. The sheer volume of papers can mean that new ideas can get lost in the sea of information, and as the annual number of papers in a field grows, the diversity of citations shrinks, with authors tending to cite already well-cited papers.

“Rather than causing faster turnover of field paradigms, a deluge of new publications entrenches top-cited papers, precluding new work from rising into the most-cited, commonly known canon of the field,” the authors write. “The more is better; quantity metric-driven nature of today’s scientific enterprise may ironically retard fundamental progress in the largest scientific fields.”

Read the paper at doi.org/10.1073/pnas.201656918

FEEDBACK CONSIDERATIONS FOR BIODIVERSITY–ECOSYSTEM RESEARCH

In some parts of our lives, we are aware that humans, animals, and plants interact to shape the biodiversity of ecosystems in dynamic ways. Yet in other parts of our collective lives, we aren’t benefiting fully from a scientific understanding of biological feedback.

In The Proceedings of the Royal Society B, SFI External Professor Mary L. O’Connor (University of British Columbia) and colleagues argue that public policy would benefit greatly if it were informed by the science of biological feedback. The research team investigated seven outstanding knowledge gaps, which can be addressed through an ambitious multidisciplinary research agenda, to clarify the ecological consequences of biodiversity feedbacks. Ultimately, the authors hope that by proposing better models of biological feedback, their work will help initiate a new feedback loop in scientific-political collaboration.

Read the paper at doi.org/10.1098/rspb.2021.0763

CHANGING SOCIAL INEQUALITY FROM FIRST FARMERS TO EARLY STATES IN SOUTHEAST ASIA

In a study published by the National Academy of Sciences, SFI External Professor Amy Bogard (University of Oxford) and colleagues documented the distribution of valuable artifacts across Southeast Asian gravesites over an era that spans from the arrival of farming to the emergence of early states. Using the Gini coefficient to measure a concentration of wealth for each collection of sites, the researchers determined which kinds of historical events caused spikes in inequality. They found that during the Bronze Age, inequality grew when groups of elites held restricted ownership of valuables like copper-based axes and jewelry. Additionally, the arid climate that prompted a shift to wet-rice farming gave rise to the first political states, and with them, new inequality.

Read the paper at doi.org/10.1073/pnas.2105589118