IAS

Fall 2019

The Institute Letter

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From Bewilderment to Clarity

James Peebles
2019 Nobel Prize Laureate on General Relativity

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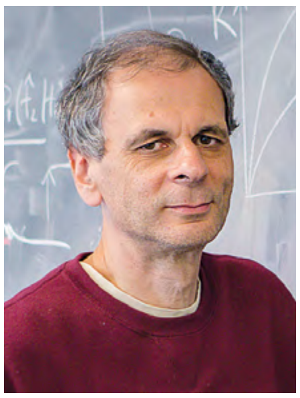
IAS The Institute Letter

Institute for Advanced Study — Fall 2019

Theoretical Neuroscientist Misha Tsodyks Joins School of Natural Sciences Faculty

Advancing a better understanding of human cognition


ANDREA KANE

Misha Tsodyks

Michail "Misha" Tsodyks, a world-leading theoretical neuroscientist, has been appointed C.V. Starr Professor in the Institute's School of Natural Sciences, effective July 1, 2019.

The research of Tsodyks, who is a Professor in the Department of Neurobiology at the Weizmann Institute of Science in Israel and a Visiting Professor at Columbia University, is focused on theoretical neuroscience, in particular on identifying neural algorithms that define functions of cortical systems. His analytical and numerical results have also had a strong impact on advancing a quantitative understanding of brain function and human cognitive abilities.

"Broad in scope and exacting in detail, Misha's exploration of neural mechanisms of cognition has propelled the field forward. He has demonstrated the importance of sparsity in neural networks, clarified the mechanisms of short-term synaptic plasticity, and provided deep insights into working memory," said Robbert Dijkgraaf, IAS Director and Leon Levy Professor. "As a theoretical neuroscientist, physicist, and quantitative researcher, Misha will complement and enhance the work of the Simons Center for

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Trailblazer Jacob Lurie Joins School of Mathematics Faculty

Constructing foundations and building bridges between fields


DAN KOMODA

Jacob Lurie

Jacob Lurie, who has made transformative contributions to mathematics through his work on derived algebraic geometry and infinity categories, has been appointed Professor in the Institute's School of Mathematics, effective July 1, 2019.

Lurie's ideas in modern algebra, geometry, and topology provide novel frameworks that guide current research, unite seemingly disparate fields, and expand upon the foundations of mathematics. Singularly original in his approach, Lurie's perspective is shaping a new generation of mathematics with deep influence across the field. Previously a Professor of Mathematics at Harvard University, Lurie has also held an Associate Professorship at the Massachusetts Institute of Technology.

"As both an architect and synthesizer of ideas, Jacob's impact is twofold: constructing the foundations for important areas in mathematics and building bridges between fields," said Robbert Dijkgraaf, IAS Director and Leon Levy Professor. "The Institute has been home to some of the greatest minds in modern algebra, homotopy theory and algebraic geometry, including Michael

(Continued on page 17)

Medievalist Suzanne Conklin Akbari Joins School of Historical Studies Faculty

Revealing new meanings and points of entry into literary texts relevant to our present

Suzanne Conklin Akbari, widely recognized for her intellectual range and interdisciplinary accomplishments in the field of Medieval Studies, has been appointed Professor in the Institute's School of Historical Studies, effective July 1, 2019.

Specializing in medieval literature, Akbari is involved in various projects to expand the range and methods of exploring texts from the Middle Ages, including a new Mellon Foundation–funded study of "The Book and the Silk Roads." The author and editor of several landmark publications, Akbari was previously Professor of English and Medieval Studies and Director of the Centre for Medieval Studies at the University of Toronto—the largest and best-known program of its kind in North America—where she served as a doctoral student advisor. Her research there focused on the intersection of English and comparative literature, ranging from Neoplatonism and science in the twelfth century to national identity and religious conflict in the fifteenth century.

"Suzanne has redefined the standard model of studying the Middle Ages. Her innovative and inclusive approach ventures beyond preconceived boundaries, bringing the variegated cultures and traditions of the time into conversation with one another and offering a unique and global perspective of the past," said IAS Director and Leon Levy Professor Robbert Dijkgraaf. "Undoubtedly, the comparative and expansive nature of her work will produce fascinating


DAN KOMODA

Suzanne Conklin Akbari

connections across the disciplines at IAS, and as a literary studies scholar, Suzanne's arrival will mark an exciting new beginning for the School of Historical Studies."

Her first monograph, *Seeing Through the Veil: Optical Theory and Medieval Allegory* (University of Toronto Press, 2004), is a study that explores the affinities between allegory and vision, making the fundamental claim that medieval theories of knowledge are closely related to optical theories. In a work encompassing science, philosophy, literature, and art history, Akbari traces the evolving relationship between sight and knowledge as manifested in a range of poetic texts.

Akbari's second monograph, *Idols in the East: European Representations of Islam and the Orient, 1100–1450* (Cornell University Press, 2009), explores the relationship between Islam and Christianity through the lens of various medieval texts, philosophical treatises, works of art, maps, historical chronicles, and encyclopedias. Her investigation reveals how medieval European Christian writers and readers understood and explained the differences they saw between themselves and the Muslim "Other" and illuminates the tangled relationship between colonial attitudes and modern racism and anti-Semitism.

"Suzanne's scholarship is not only marked by an extensive engagement with

(Continued on page 7)

News of the Institute Community

Suzanne Conklin Akbari, Professor in the School of Historical Studies, has coedited *How We Read: Tales, Fury, Nothing, Sound* (Punctum Books, 2019).

Yve-Alain Bois, Professor in the School of Historical Studies, will give the 2020 A.W. Mellon Lectures in the Fine Arts at the National Gallery of Art in Washington, D.C.

Didier Fassin, James D. Wolfensohn Professor in the School of Social Science, has been elected the Annual Chair of Public Health at the Collège de France for 2019–20. Additionally, Fassin has coedited *A Time for Critique* (Columbia University Press, 2019) with Bernard E. Harcourt, Visiting Professor (2016–17) in the School.

Juan Maldacena, Carl P. Feinberg Professor in the School of Natural Sciences, has been awarded an honorary doctorate from the University of Buenos Aires.

Alondra Nelson Harold F. Linder Professor in the School of Social Science, has been selected to serve on the Obama Presidency Oral History Advisory Board. Additionally, Nelson has been inducted as the 2019 Ernest W. Burgess Fellow of the American Academy of Political and Social Science.

Peter Sarnak, Professor in the School of Mathematics, has been awarded the 2019 Sylvester Medal by the Royal Society.

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Questions and comments regarding the *Institute Letter* should be directed to Kelly Devine Thomas, Editorial Director, via email at kdthomas@ias.edu or by telephone at (609) 734-8091.

Issues of the *Institute Letter* and other Institute publications are available online at www.ias.edu/publications.

Articles from issues of the *Institute Letter* are available online at www.ias.edu/ideas.

To receive monthly updates on Institute events, videos, and other news by email, subscribe to *IAS eNews* at www.ias.edu/enews.

Sabine Schmidtke, Professor in the School of Historical Studies, has been elected to the Académie des Inscriptions et Belles-Lettres as a Foreign Corresponding Member, along with two former Members. Additionally, Schmidtke has prepared for publication and introduced, with Hassan Ansari, Long-term Member in the School, *The Zaydi Reception of Bahshamite Muʿtazilism: Facsimile Edition of MS Shiraz, Library Of The Faculty of Medicine at the University of Shiraz (ʿAllāma Ṭabāṭabāʾī Library), Majmūʿa 102* (Gorgias Press, 2019). Schmidtke has also coauthored *Muslim Perceptions and Receptions of the Bible: Texts and Studies* (Lockwood Press, 2019).

Akshay Venkatesh, Robert and Luisa Fernholz Professor in the School of Mathematics, has been awarded an honorary doctorate from the University of Western Australia.

Patrick J. Geary, Professor Emeritus in the School of Historical Studies, is one of four principal investigators who will lead the multidisciplinary project HistoGenes, for which the Institute for Advanced Study and its international partners have been awarded a €10 Million ERC Synergy Grant from the European Research Council.

Robert P. Langlands, Professor Emeritus in the School of Mathematics, has been appointed a Companion of the Order of Canada.

Peter Paret, Professor Emeritus in the School of Historical Studies, has coauthored and edited *Krieg, Geschichte, Theorie: Zwei Studien ueber Clausewitz* (Miles-Verlag, 2018).

Robbert Dijkgraaf, Director and Leon Levy Professor, has been awarded the inaugural Iris Medal for Excellent Science Communication in the Netherlands.

The Institute for Advanced Study has selected Sir James Wolfensohn, Chair Emeritus of the Board of Trustees, as the recipient of the 2020 IAS Bamberger Medal.

Alex Eskin, Member in the School of Mathematics, has been awarded the 2020 Breakthrough Prize in Mathematics. Additionally, the 2020 Breakthrough Prize in Fundamental Physics has been awarded to the scientists of the Event Horizon Telescope Collaboration, including Lia Medeiros, Member in the School of Natural Sciences, as well as former Members in the School: Dimitrios Psaltis (2001–03); Buell Jannuzi (1990–95); Charles Gammie (2006–07); Ramesh Narayan (1987–88, 1994, 2001, and School of Mathematics Visitor, 1989); and Feryal Özel (2002–05). The 2020 New Horizons in Mathematics Prize has been awarded to Emmy Murphy, von Neumann Fellow in the School of Mathematics. The 2020 New Horizons in Physics Prize has been awarded to Simon Caron-Huot, Long-term Member (2009–14) in the School of Natural Sciences, with Pedro Vieira.

Rashid Sunyaev, Maureen and John Hendricks Distinguished Visiting Professor in the School of Natural Sciences, has received the 2019 Dirac Medal, along with Viatcheslav Mukhanov, Member (2002) in the School, for their profound impact on modern cosmology.

Karen Uhlenbeck, Distinguished Visiting Professor in the School of Mathematics, will be awarded the 2020 Leroy P. Steele Prize for Lifetime Achievement from the American Mathematical Society. Additionally, Uhlenbeck has been named a Fellow of the Association for Women in Mathematics, along with three former Members.

Celestial Bodies (Catapult, 2019), translated by Marilyn Louise Booth, Member (2018) in the School of Historical Studies, has been awarded the Man Booker International Prize 2019.

Incidental Archaeologists: French Officers and the Rediscovery of Roman North Africa (Cornell University Press, 2018) by Bonnie Effros, Member (2013–14) in the School of Historical Studies, has been awarded the 2019 Alf Andrew Heggoy Book Prize by the French Colonial Historical Society.

The Interpretive Methodologies and Methods Conference Group of the American Political Science Association has announced the creation of "Routledge's Lee Ann Fujii Award for Innovation in the Interpretive Study of Political Violence," named in honor of the late Lee Ann Fujii, Member (2016–17) in the School of Social Science.

Daniel Freedman, Member (1967–68, 73–74, 86–87) in the School of Natural Sciences, has been awarded the 2019 Special Breakthrough Prize in Fundamental Physics, along with collaborators Sergio Ferrara and Peter van Nieuwenhuizen, for their theory of supergravity.

Michael G. Hanchard, Member (2014–15) in the School of Social Science, has been awarded the 2019 Ralph J. Bunche Award for *The Spectre of Race: How Discrimination Haunts Western Democracy* (Princeton University Press, 2018).

Jay Pasachoff, Member (1989–90) in the School of Natural Sciences, has received the 2019 Klumpke-Roberts Award from the Astronomical Society of the Pacific.

James Peebles, Member (1977–78) and Visitor (1990–91, 1998–99) in the School of Natural Sciences, has been recognized with the 2019 Nobel Prize in Physics. Peebles, who is awarded one half of the prize, is recognized "for theoretical discoveries in physical cosmology."

Tracy Slatyer, Junior Visiting Professor (2018–19) and Member (2010–13) in the School of Natural Sciences, Thomas Hartman, Member (2010–13) in the School, and Lillian B. Pierce, von Neumann Fellow (2017–18) in the School of Mathematics, have been named recipients of the Presidential Early Career Award for Scientists and Engineers.

Selected by the National Endowment for the Humanities, Father Columba Stewart, Member (2016–17) in the School of Historical Studies, delivered the 2019 Jefferson Lecture in the Humanities on October 7.

Jörn Rausing Appointed to Board of Trustees

Jörn Rausing

The Institute for Advanced Study has appointed Jörn Rausing to its Board of Trustees, effective May 4, 2019.

Jörn Rausing is a non-executive director of the Tetra Laval Group Board since 1991 (and alternate director of the Tetra Pak Group Board since 1985). Additionally, Rausing serves as Tetra Laval Group's Head of Mergers and Acquisitions and is the Chairman of the Remuneration Committee of the Tetra Laval Group Board.

Rausing is also a board member of Alfa Laval AB and DeLaval Holding AB and of Ocado PLC. ■

ANDREA KANE

Five New Faculty and 272 Visiting Scholars Join IAS for 2019–20 Academic Year

New Faculty research extends from literary studies to neuroscience

With the opening of the academic year on September 23, the Institute for Advanced Study welcomed an extraordinary group of visiting scholars and new Faculty—Suzanne Conklin Akbari, Jacob Lurie, Alondra Nelson, Jim Stone, and Misha Tsodyks—who bring new fields and depth of study to IAS.

The new Professors are among the Institute's twenty-six permanent Faculty who will work alongside 272 visiting scholars and scientists from 107 institutions and 22 countries in 2019–20.

This year's new Faculty expand the diverse scope of IAS research, contributing new perspectives in literary studies; modern algebra, geometry, and topology; the sociology of science; computational astrophysics; and neuroscience. Their collective work within these fields is widely acclaimed for its originality, uniting various traditions of thought, and accelerating knowledge.

"It is my pleasure to welcome new and returning Members and Faculty to our IAS community for another academic year that will allow time and space for independent study as well as dialogue," said Robbert Dijkgraaf, Institute Director and Leon Levy Professor. "Given the freedom to take risks, exchange ideas, and pioneer new methodologies, our annual visiting scientists and scholars are able to take their research in unexpected directions. I look forward to seeing how this year's diverse class will enhance and test our perceptions of the world."

Among this year's new Members are Cord Whitaker in the School of Historical Studies, an Associate Professor at Wellesley College who is interested in the history and development of race and racism in medieval English literature; Lia Medeiros, a postdoctoral fellow in the School of Natural Sciences who has been recognized with the 2020 Breakthrough Prize in Fundamental Physics as a member of the Event Horizon Telescope Collaboration, which produced the first image of a black hole in April 2019; Chris J. Maddison, a Senior Research Scientist at DeepMind who joins the School of Mathematics as part of its special year on Theoretical Machine Learning; and Julia Ott, Associate Professor of History at the New School for Social Research, who will examine the origins of venture capital as part of the School of Social Science's annual theme "Economy and Society." To learn more about these scholars and their research, visit www.ias.edu/idea-tags/scholars. ■

Joanne Lipman Serves as First Peretsman Scully Distinguished Journalism Fellow

IAS launches Distinguished Journalism Fellowship program

DAN KOMODA

Joanne Lipman

The Institute for Advanced Study has introduced a Distinguished Journalism Fellowship program to underscore its commitment to truth and innovation in all forms, including the vital role of a free and informed press. With support from the Scully Peretsman Foundation, Joanne Lipman joins the program in 2019 as the first Peretsman Scully Distinguished Journalism Fellow. Lipman, one of the world's leading journalists, is a bestselling author, CNBC Contributor, and former Chief Content Officer of Gannett and Editor-in-Chief of *USA Today.*

"This fellowship is a thrilling opportunity for the Institute to open its doors to new audiences through the work of some of the world's most accomplished journalists," said Robbert Dijkgraaf, IAS Director and Leon Levy Professor. "Bringing fresh perspective and national media experience, Joanne Lipman is ideally suited to inaugurate this program, and we warmly welcome her to the Institute."

Awarded to leading journalists and editors, the fellowship aims to protect journalistic freedom, encourage the transmission of novel and nuanced ideas, and advance trust in reporting. As part of the Director's Visitors program, the Distinguished Journalism Fellow will participate in lectures, panels, and broadcasts and interact frequently with Faculty and Members.

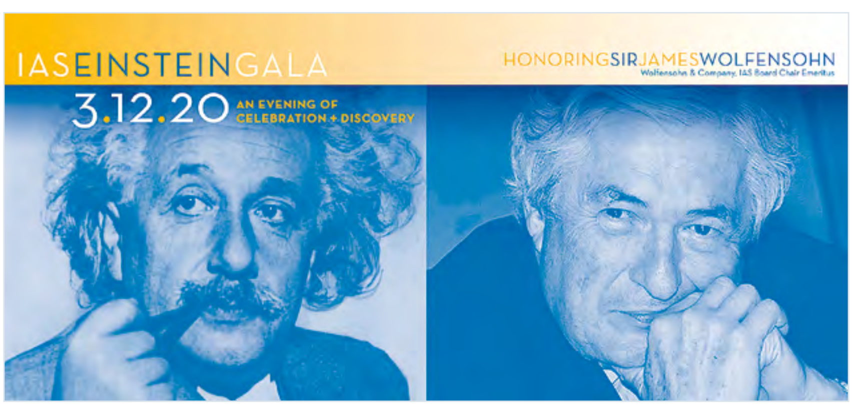
"IAS is poised to play a leading role at the intersection of media and technology. It is already home to many of the world's top researchers in digital transformation as well as the social sciences," Lipman remarked. "I'm thrilled to be joining the Institute, which is committed to truth, freedom of ideas, and the ideals of trusted journalism. I look forward to tapping into IAS's deep resources and helping to share its scholars' extraordinary work with a broader audience."

While at IAS, Lipman will investigate the impact of machine learning and artificial intelligence on the media and on journalism specifically. The bestselling author of *That's What She Said: What Men and Women Need to Know About Working Together* (William Morrow, 2018), Lipman will continue her work on gender in the workplace and engage with scholars in the School of Social Science for its theme year on "Economy and Society." ■

Sir James Wolfensohn to Receive 2020 IAS Bamberger Medal

Institute's highest honor to be presented at IAS Einstein Gala on March 12, 2020

Sir James Wolfensohn, the Institute for Advanced Study's longest-serving Board Chair (1986–2007), former President of the World Bank, and current Chairman of Wolfensohn & Company, has been selected to receive the 2020 IAS Bamberger Medal. The honor will be presented to Wolfensohn at the IAS Einstein Gala on March 12, 2020, at the Glasshouse in New York City.



"As Chair of the Institute's Board, Jim led the Institute into the twenty-first century, greatly expanded the institution's financial resources, affirmed the importance of the arts to science and scholarship, and furthered global outreach and broad respect for the IAS as one of the world's leading centers for intellectual inquiry," said Robbert Dijkgraaf, Institute Director and Leon Levy Professor. "His exceptionally diversified achievements as an individual are equaled by his strength of character, good judgment, and sense of humor. The Institute is proud to honor our longtime leader, colleague, and wonderful friend with the IAS Bamberger Medal."

Charles Simonyi, Technical Fellow at Microsoft Corporation and current Chair of the Institute's Board, and Jim Simons, Chair of the Simons Foundation and IAS Trustee Emeritus, will serve as Honorary Chairs of the IAS Einstein Gala.

"Jim Wolfensohn is a tireless leader, motivator, and friend. His work has strengthened the mission and integrity of the Institute in innumerable ways," said Simonyi. "With adroit expertise and agility, Jim struck a rare balance between conservation and renewal to move the Institute forward."

The IAS Bamberger Medal is the Institute's highest honor, presented in recognition of visionary support of the Institute's pioneering research. The medal is named in honor of Caroline Bamberger Fuld and Louis Bamberger, the sister-and-brother philanthropists who provided the founding $5 million gift to establish IAS as envisioned by the education reformer Abraham Flexner, the Institute's founding Director. For more information about the IAS Einstein Gala, visit www.ias.edu/gala. ■

A Conversation with James Peebles, 2019 Nobel Prize Laureate in Physics

From Einstein's general theory of relativity to the origin, composition, and evolution of the universe

James Peebles, Member (1977–78) and Visitor (1990–91, 1998–99) in the School of Natural Sciences, has been awarded the 2019 Nobel Prize in Physics for his "contributions to our understanding of the evolution of the universe and Earth's place in the cosmos."

The Royal Swedish Academy of Sciences—which awarded half of the prize to Peebles, and the other half to Michel Mayor and Didier Queloz "for the discovery of an exoplanet orbiting a solar-type star"—further cites Peebles for his insights into physical cosmology, which have "enriched the entire field of research and laid a foundation for the transformation of cosmology over the last fifty years, from speculation to science. His theoretical framework, developed since the mid-1960s, is the basis of our contemporary ideas about the universe."

"Nobody has done more for our theoretical understanding of the origin, composition, and evolution of the universe than Jim Peebles," said Robbert Dijkgraaf, IAS Director and Leon Levy Professor. "Building on Albert Einstein's general theory of relativity, Jim's work allows us to reconstruct the history of the cosmos from the earliest signal emitted just after the Big Bang."

Peebles, who is currently the Albert Einstein Professor of Science, Emeritus, at Princeton University, served on the organizing committee for "General Relativity at 100," a celebration of the centennial of Einstein's general theory of relativity, organized by the Institute and Princeton University in 2015. The conference included a discussion moderated by Peebles on the seminal role of Princeton physicists, particularly John Wheeler (Member, 1937) and Bob Dicke (Member, 1970–71) and their students, in advancing an examination of general relativity.


DAN KOMODA

James Peebles at IAS in 2015 during the centennial celebration of Einstein's general theory of relativity, organized by the Institute and Princeton University. Watch the discussion moderated by Peebles on the seminal role of Princeton physicists in advancing an examination of general relativity at www.ias.edu/ideas/2015/general-relativity-at-100-conference.

At the time of the conference, Peebles spoke with the *Institute Letter* to provide some context about the resurgence of interest in Einstein's general theory of relativity, alternatively known as a theory of gravity. The following is an edited transcript of the conversation.

IL: Could you talk about the period of time when Einstein's theory of general relativity was not an active area of research?

JP: People were working in general relativity in the 1930s and 1940s. Howard Percy Robertson at Princeton University was doing interesting things. But it was quite low-key, and indeed by the mid '50s, or let us say by '58 when I arrived at Princeton as a graduate student, the usual feeling was that general relativity is an elegant theory of very limited interest. Of course, the big actors then were particle physics and quantum physics. Condensed matter was starting to heat up, but general relativity—eh, a dead end.

At about that time, a few people around the world decided that we should look more closely at gravity physics and general relativity. I think it is fair to say that the two dominant leaders were at Princeton University—John Archibald Wheeler on the theoretical side, Robert Henry Dicke on the experimental side—both beginning around 1957 or so.

I arrived at Princeton as a graduate student in 1958, when Bob Dicke was assembling a group to do experiments to test general relativity and alternative theories of gravity. I was one of Bob's two theoretical students. It was great for me, because he was doing just the sorts of things that fascinate me. He set my career.

It became clear that there was a lot to be done in gravity physics, both theory and observation. As I said, in the 1960s, only a few people were working on both sides of gravity, theory and experiment. It was an exciting time that offered me lots of room for exploration of new ideas. But of course we couldn't anticipate that this work would grow into the present big science.

IL: Why was general relativity not interesting before then?

JP: It was not interesting because no one thought to look, and because the technology needed to make the experimental part interesting was not available before the war. Research in World War II was enormously transformative. And a big part of that was that the technology developed during the war made an enormous difference to what could be done in the laboratory.

One talks about the atomic bomb as transformative, but radar was perhaps even more so, and a lot of that development happened at the radiation laboratory based on the MIT campus, where Bob Dicke worked, inventing electronics—in particular, the Dicke radiometer. Twenty years later, we returned to the Dicke radiometer: his Gravity Research Group used it to discover and explore the properties of the cosmic microwave background radiation.

IL: What problems were you personally working on at the time?

JP: My thesis was on a test of whether the strength of the electromagnetic interaction changes with time. A measure of the electromagnetic interaction is termed the fine-structure constant. It is a constant in standard physics, but Bob Dicke was interested in whether that number changes with time.

I could find lots of data that constrain how much it could have changed. I could also make a little theory about how it might change, one that could account for all the constraints that we had, and what new measurements could be made to further constrain and test the theory. It was an exploration of a possibility. There still is lots of interest in the question, "Does this fine-structure constant evolve?"

IL: What is your sense about gravity's place in physics?

JP: I love physics in all its manifestations, and I think of gravity as one of the parts of physics. I don't think of it or cosmology as particularly special; the physics of materials is just as fascinating as the physics of gravity. When I was a graduate student, it was said that particle physics is the queen of science, the rest engineering. A respected senior physicist said that to me. I was shocked.

Particle theory is, indeed, magnificent, but I don't see it as the queen of physics, or that there is such a thing as a central and fundamental core of physics. There are so many aspects to physics, each fascinating, with research on each operating according to the conditions one has to live with.

Dirac wrote, approximately, that "the physical laws of chemistry are completely known." That very well may be true in principle, but in practice, chemistry is not solved. Chemistry today uses quantum mechanics, to be sure, but it is following its own hierarchy of approximations that are quite different from the hierarchy that leads you down to the Higgs. I am sure chemistry and particles are tightly related, but I don't know that their relation goes entirely one way, that if you understand particle physics, you can understand chemistry. And I am pretty sure that if you understand chemistry quite well, you won't necessarily understand particle physics. When both are better understood, they might merge in some deeper level of the hierarchy of successive approximations. But that is for the future.

When we learn how the brain works, we will have a whole new hierarchy of theories that someday, somehow, may connect with particles and chemistry on some deep level. And I expect gravity physics is part of this game too, somehow.

IL: When you think about the theory of general relativity back when you began testing it and now, how has it changed for you?

JP: When I came to Princeton as a graduate student, I had no interest in gravity. Back then, there was a gravity theory, the general theory of relativity, but it had close to negligible empirical support. I first learned elements of general relativity because it was on the graduate general exams, but I thought the aspects I was exposed to were kinda Mickey Mouse. But I fell under Bob Dicke's influence, I liked his analysis of data, and that showed me that I had better understand general relativity theory. To me, previously, it seemed empty. I much prefer theories that involve measurements, which is the case for general relativity now.

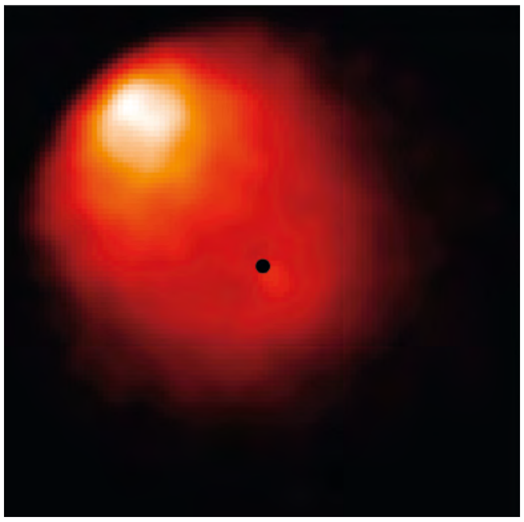
It is to me more than a little startling to consider how well tested that theory has become. I am deeply impressed that Einstein's vision of 100 years ago has survived. Of course, great challenges remain. Two challenges are to understand how to reconcile the quantum and relativity principles, and how the world operates within this theory to be discovered.

We have the more immediate and deep problems of understanding dark matter and dark energy. I am particularly fascinated by the manifestations of the properties of dark matter in the mass concentrations known as galaxies. Despite great progress in the theory of galaxy formation, there are fascinating properties of galaxies that remain poorly understood. That is in part because galaxies are complicated, but I can't resist the thought that it may be in part because we don't have an adequate understanding of the nature of dark matter. So a lot of my effort these days, when I'm not being a historian, is thinking about properties of galaxies and lessons they might be offering us about gravity physics and dark matter. I like this because galaxies have lots of properties that can be measured and compiled, and it seems to me to be a good time to sift through all these data—look for regularities, look for puzzles, and think about what they may teach us.

I am quite content to leave the unification of the quantum and relativity principles to others. I did write one paper on unification back when I was a post doc, and I remember Bob Dicke laughing and saying, "All right, go ahead and do that, get your Nobel Prize, and then come back and do some physics." ■

How Do Supermassive Black Holes Influence Their Stellar Surroundings?

Probing features of star clusters surrounding supermassive black holes



J.R. TOUMA, S. TREMAINE, AND M.V. KAZANDJIAN

Simulation of a black hole system in a lopsided state

In the paper "Order-Disorder Phase Transition in Black-Hole Star Clusters," published in *Physical Review Letters* on July 12, 2019, Scott Tremaine, Richard Black Professor in the Institute's School of Natural Sciences, and coauthors have taken the first steps toward understanding the collective orbital patterns that emerge in star clusters surrounding a supermassive black hole.

Tremaine, with coauthors Jihad Touma, a former Member and Visitor in the School of Natural Sciences now at the American University of Beirut, and Mher Kazandjian of Leiden University, used a series of numerical models and simulations to show that black hole star clusters can undergo a phase transition from a spherical state to a lopsided state when they are cooled below a critical dynamical temperature. This phase transition, in some senses, is similar to the phase transition that occurs when a liquid changes into a solid. Just as molecules may shift from a disordered liquid state to a state where they are frozen in place, these star clusters are capable of achieving equilibrium in either a disordered (spherical) or an ordered (lopsided) structure, depending on their properties and environment.

A lopsided nuclear star cluster surrounding a supermassive black hole is seen in Hubble Space Telescope images of the nearby Andromeda galaxy, while our Milky Way galaxy and M87—whose supermassive black hole was recently imaged by the Event Horizon Telescope—harbor spherical clusters. For more distant galaxies, the nuclear star clusters are too small to be imaged by existing telescopes, but the cluster shapes may strongly influence the rates of transient events that can be observed, such as flares from tidally disrupted stars and gravitational wave signals from stars spiraling into the black hole.

"These systems exhibit surprisingly rich behavior, with remarkable parallels to well-studied laboratory phenomena such as freezing and ferromagnetism," said Tremaine. "These new phenomena may dramatically change our understanding of the environment of supermassive black holes and enhance our ability to understand the rates and properties of supermassive black hole mergers, consumption of stars by black holes, and other phenomena at the centers of galaxies." ■

Q&A with Lia Medeiros

On using astronomical objects to test fundamental physics

ANDREA KANE

Lia Medeiros, a Member and astrophysics postdoctoral fellow in the School of Natural Sciences, is interested in using astronomical objects and phenomena to test fundamental theories of physics. She is a winner of the 2020 Breakthrough Prize in Fundamental Physics as a member of the Event Horizon Telescope Collaboration, which produced the first image of a supermassive black hole in April 2019.

What question within your field do you most want to answer and why?
Currently, my focus is on the Event Horizon Telescope (EHT); I am trying to determine whether black holes in space behave the way we expect based on our current understanding of gravity. In general, I am interested in using astronomical objects and phenomena to learn more about gravity.

What do you hope the impact of your research will be, now or in the future?
I hope that results such as the recent EHT image of M87 and the many gravitational wave detections by the LIGO/VIRGO collaboration are just the beginning, and that we will continue to use astronomical black holes to test fundamental physics.

How do you describe your work to friends and family?
I frequently try to describe what the recent EHT image of the black hole in the center of M87 actually shows. The main idea I try to explain is that the dark region in the center of the image is what we like to call the black hole shadow, or the shadow that the black hole casts on the surrounding emission. The black hole shadow that is seen in the image is significantly larger than the size that the event horizon would have if it were observable. ■

Read more of Medeiros's Q&A at www.ias.edu/ideas/lia-medeiros.

Group from the SRG consortium, including scientists, among them Rashid Sunyaev (first row, fifth from right), engineers, and ballistic specialists in front of the Proton-M—a three-stage rocket, booster, and spacecraft, exceeding 57 meters in length altogether.

SRG Spacecraft to Create X-Ray Map of Universe

Rashid Sunyaev serves as SRG's Scientific Head in Russia

A pioneering mission that traces its roots back to the Soviet Union achieved liftoff on July 13, 2019. Rashid Sunyaev, Maureen and John Hendricks Distinguished Visiting Professor in the School of Natural Sciences, helped conceive of the venture more than fifteen years ago.

HAVE YOU SEEN YOUR BODY IN X-RAYS? IT LOOKS COMPLETELY DIFFERENT. WE WILL DO THE SAME WITH THE UNIVERSE.

Sunyaev—the recipient of the 2019 Dirac Medal for contributions to our understanding of the early universe and to the physics of the cosmic microwave background—serves as the Scientific Head of the project in Russia and will lead scientific analysis and operation planning in Russia for the joint German–Russian mission called Spectrum-Roentgen-Gamma (SRG). Sunyaev, together with Yakov Zeldovich, predicted what has become known as the Sunyaev-Zeldovich effect, a decrease in brightness of the cosmic microwave background in the direction of rich clusters of galaxies. The SZ effect makes it possible to use clusters of galaxies as a powerful tool of observational cosmology.

"Have you seen your body in X-rays? It looks completely different," said Sunyaev, who spoke with a *Nature* reporter about the SRG mission. "We will do the same with the universe."

SRG aims to detect about 100,000 clusters of galaxies of 200 trillion solar masses or greater in the observable universe. The mission should detect up to three million supermassive black holes, as many as 700,000 stars in the Milky Way, and various X-ray sources throughout our galaxy, from accreting white dwarf stars to supernovae remnants. In addition, it will probe dark energy (the mysterious force involved in the accelerating expansion of the universe), the distribution of ordinary matter and dark matter (which determines how and where galaxies form), and look for direct hints as to the nature of dark matter particles. ■

From Bewilderment to Clarity

When seemingly intractable problems give way to "aha! moments"

BY SUZANNE CONKLIN AKBARI

To be bewildered is, literally, to be lost in the woods. Not lost in the beautiful and well-marked paths that wind through the Institute forest but trapped and disoriented in a dangerous place with the fear that you might never escape. The fourteenth-century poet Dante describes such a space in the opening lines of his *Commedia*, and the feeling of terror he experienced when "the right way was lost." Metaphorically, to be bewildered is to be adrift mentally, having lost your bearings and being in a state of confusion.

Yet the state of bewilderment is also fundamental to the search for insight. It is a necessary first step in the effort to get to a point of greater clarity and to see the right way even when—especially when—it seems to be lost. Popular accounts of mathematicians and scientists feature moments when a seemingly intractable problem gives way to an "aha! moment," the sudden realization that (in hindsight) appears to be obvious. One famous example concerns the organic chemist August Kekulé, who in the mid-nineteenth century discovered the ring structure of the benzene molecule: Kekulé stated that he had had a dream in which a snake was eating its own tail and, upon waking up, realized in a flash the circular shape of the molecule. Long hours of thinking, studying, and puzzling—of bewilderment—are the necessary precursor to this abrupt moment of insight.

An illustration from a manuscript of a thirteenth-century encyclopedia, Gossuin de Metz's *Image du Monde*

For humanists, the experience of bewilderment—and the sudden flash of clarity that sometimes follows—plays out in a different way. To provide a sense of this movement from bewilderment to clarity, let me describe the illustration shown here, taken from a manuscript of a thirteenth-century encyclopedia, Gossuin de Metz's *Image du Monde* (London, British Library Royal MS 19.A.IX, fol. 149r). This is a picture of everything: it shows an image of the cosmos, with the Earth at its center and the gaping mouth of hell nestled within it. The circular form of the planetary sphere is surrounded by the four elemental spheres of earth (black), water (blue), air (golden), and fire (red), which are in turn encircled by the seven planetary spheres, followed by the sphere of the fixed stars, the empyrean sphere, and the realms of the celestial heavens. It is fair to say that the image is bewildering, even for someone who knows a fair amount about medieval visions of the cosmos and who can recognize the elemental and celestial spheres that those many-hued circles represent. But more questions remain: What are these figures at the corners? Why is the central slice, so to speak, of the spheres cut through and painted white? What does each circle represent? It would be possible to write paragraph upon paragraph explicating the four evangelists at the corners, the symmetries and variations in the spherical system, and the figure of Christ at the top, seated on a sepulchre-like throne and holding in his hand a round sphere or orb. That orb is a symbol of power, but it is also a microcosm or little world that represents in miniature the entire cosmos that is also depicted on the page before us.

In other words, the clarity that emerges from the initial state of bewilderment upon seeing this image does not arise simply from a knowledge of the historical context that lies behind the image. It also comes from reflecting on the image's various parts, imagining how they fit together, realizing—with a jolt—that the object in the left hand of Christ is also the entire scope of the cosmos depicted here. When I think back to my own experience as a researcher in historical fields, interested in the literature, art, philosophy, theology, and science of the Middle Ages, and I try to identify the "aha! moments" in my own intellectual trajectory, two examples stand out, each of them associated with a major research project and subsequent book. Early on, when I was working on the history of optics, I was trying to understand how medieval writers might have understood phenomena of refraction such as the rainbow, or the spectrum of colors produced by a prism. Thinking about reflection and refraction (as these were theorized by twelfth-century science), I sat in a coffee shop twisting around and around the ring on my finger. Looking at it intently, so that my sight went in and out of focus, I could see that the stone both reflected images of things around it and also refracted light in a burst of the spectrum. This was (I suddenly realized) the same simultaneous reflected and refracted vision that was being described in some obscure and technical passages on vision that I was studying in the thirteenth-century *Roman de la Rose*. This experience happened over thirty years ago, in the spring of 1989, but I can still see that ring in my mind's eye and remember vividly the flash of pleasure that came with that moment of insight.

Having had that first experience of bewilderment giving way to clarity, I recognized it immediately when it came a second time. I was well into the research project that became my second monograph, on medieval depictions of Islam and the Orient, but I had been having a hard time seeing how the work as a whole might be conceptually organized. I knew that depictions of Muslims as polytheistic idolaters, who were alien in terms of their belief system, was one vector of the project, but I also knew that it would be necessary to take stock of how medieval writers accounted for the range of bodily diversity in terms of climate—that is, how they conceived of anatomical and physiological differences in ways that would ultimately lead to a racialized sense of the Orient. It was unclear to me how I might bring these vectors of the project together, though I knew that they were related. Walking to meet a friend one afternoon—I can remember exactly where I stood on the sidewalk, and remember the level of the sun in the sky—I suddenly saw how to organize the two halves of the book about the twinned and related concepts of orientation and Orientalism, putting spatial relations at the center of the analysis whether alterity was grounded on religious orientation or on Oriental identity. I stopped in mid-step, pulled a pencil out and scrawled a diagram of the chapter headings for the whole book, standing on the sidewalk that late afternoon.

These "aha! moments" are, in some ways, very different from those experienced by the mathematicians and scientists with whom I began. For humanists, the goal is rarely to solve a puzzle or establish an irrefutable proof: instead, the goal is to formulate a line of questioning, or to establish a structure within which to consider a set of problems or a discursive formation, in order to shift the terms of the field in a way that opens up new areas to be explored. The very best scholars in the humanities do exactly this: they open up new spaces for investigation. Yet even though there is a gap between the "aha! moments" of mathematicians and scientists, on the one hand, and those of humanists, on the other, it is also a fact that my own earliest intellectual formation came in the world of numbers. Perhaps that's why I tend to see "aha! moments" as bridging the gap between mathematics, sciences, and humanities.

As a child, I loved to read. I was unhappy in school, though, probably because our small town didn't have a very challenging school system. That world changed dramatically when, in fifth grade, we were given "Spectrum" math books. These books—so named because they started at the basic level (with a red cover) and moved up, level by level, through orange, yellow, green, blue, and purple—were a life saver. You could work at your own speed during math period, and if you finished your other work early in another period, you could pick up the "Spectrum" books and continue to work on your own. I went through four of those books—orange, yellow, green, blue—in fifth grade. In sixth grade, I finished purple and then math class became very boring indeed. It was the same in seventh grade. I skipped eighth grade, and ninth grade was a little better, but not much. I was still very bored. Then one day in the spring I read in the *New York Times* that there was a new program beginning at Johns Hopkins, called the "Program for Verbally Gifted Youth" (PVGY), a new counterpart to an existing longitudinal "Study of Mathematically Precocious Youth" (SMPY). After a couple of phone calls, and after talking my mother into driving me to Baltimore, I was at the Ames Building taking the SAT Verbal section, to see if I could place into the PVGY program. The postdoc who gave me the test suggested that I take the math portion too, just to see what the score was like. I placed into both programs and spent the summer I turned fourteen living in Baltimore, in my uncle's spare bedroom, and taking the bus into the Hopkins campus.

That summer was transformative. I had never been so happy. There was a limitless space, it seemed, for growth and for thinking. In some ways, it was like

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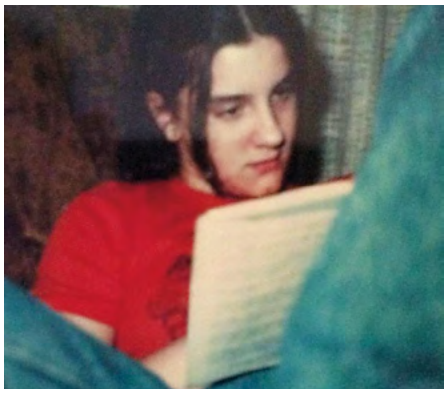
BEWILDERMENT *(Continued from page 6)*

paradise. In some ways, it was also dangerous: bewilderment, without the hope of escape, lurked in the background. My summer was wonderful, but I was aware that it was not that way for every student in the program. At thirteen going on fourteen, I was one of the oldest, and one of only a few girls in the math study that year. Most of the other students were twelve, and I remember one eleven-year-old named Aaron who sat behind me. We were working at our desks when I heard the sound of sobbing behind me. He was struggling with a problem, in tears, saying over and over, "I just can't get it." I encouraged him, and one of the older teenaged boys who were our mentors came over to help, but the moment stuck with me. The sense of freedom that summer was always accompanied by the sense of possible danger, just as the feelings of bewilderment were swept away by the moments of shining clarity. Solving a difficult problem brought with it an intoxicating surge of pleasure.



Suzanne Conklin Akbari, reading, 1979

In joining IAS, one of the most curious features, for me, is being once again in the company of mathematicians and scientists in a way that I have not been since I was fourteen years old. In the university setting, even though we have colleagues across the disciplines, spanning mathematics, sciences, and humanities, we are all in our own little boxes, separated by our curricula and our research programs. At the Institute, while each School certainly has its own character and researchers' work is highly specialized, there is nonetheless a sense of common purpose and shared environment. We inhabit the same space—the same woods—and not just in the literal sense. We share the experience of bewilderment, and the perpetual yearning for clarity. ■

Suzanne Conklin Akbari joined the Institute's School of Historical Studies as Professor of Medieval Studies in July 2019. Her research has expanded the range and methods of exploring texts from the Middle Ages, pushing the boundaries of traditional readings and exploring shared histories. She is interested in how ideas still current today—national identity, religious law, ways of dividing up time into periods—emerged from an interconnected medieval world. She also cohosts a bimonthly podcast on literature at www.megaphonic.fm/spouter.

AKBARI *(Continued from page 1)*

distinct aspects of literary theory, but also driven by what may be described as an experimental tension that, emanating from deep and extensive textual knowledge, pushes the boundaries of traditional readings and takes the object (a text, a corpus, even a canon) onto new shores," said Nicola Di Cosmo, Luce Foundation Professor in East Asian Studies. "Her work continues to reveal new meanings and points of entry into a past that, as she reminds us, remains relevant to our present."

Each one of the four edited volumes she has produced to date has been praised as a venture in a new direction. *How We Write: Thirteen Ways of Looking at a Blank Page* (Punctum Books, 2015)—rather than serving as an instruction manual—features essays by thirteen authors reflecting on their own unique writing processes, highlighting its messiness, moments of discovery, and unpredictability. *A Sea of Languages: Rethinking the Arabic Role in Medieval Literary History* (University of Toronto Press, 2013) is a collection of essays that interpret the medieval world from a distinct "Mediterranean" perspective, challenging the notion of medieval European literature's insularity and highlighting the influence of Arabic poetry, music, and philosophy. *The Ends of the Body: Identity and Community in Medieval Culture* (University of Toronto Press, 2013) reveals the various uses and meanings of the body as shaping private and public spaces, personal identities, and whole communities. *Marco Polo and the Encounter of East and West* (University of Toronto Press, 2008) confronts the ingrained concept of binary opposition between East and West, offering a perspective of cultural, economic, and linguistic exchange rather than conquest and conflict.

"From childhood, I have been fascinated by the Institute's very special combination of complete intellectual freedom and a multidisciplinary environment that ranges from mathematics to the sciences to the humanities," remarked Akbari. "Joining this community of researchers will, I am certain, push me in unexpected directions and unleash new sources of creativity. I am both honored and delighted to join the School of Historical Studies."

Akbari is currently working on two new monographs, which further evidence the contributions of literature to historical thought. The first book, *Small Change: Metaphor and Metamorphosis in Chaucer and Christine de Pizan*, surveys the phenomenon of change as it was understood in England and France in the years around 1400. The second work, *The Shape of Time*, will examine the structure of world histories written between the First Crusade and the fall of Constantinople in order to take stock of how premodern people saw themselves situated in history, providing useful insight into medieval perspectives on temporality, as well as casting a light on our own ways of conceptualizing our historical moment—what is "modern" and what is "medieval."

While Akbari's research has often been conveyed through writing, she has found in lectures—specifically her Literary Tradition class—the power to captivate and share the emotion of reading with students. Seeking to capture this feeling of spontaneity and excitement as inspired by the written word, and to provoke the desire to read, she has created and hosts with a former student, Chris Piuma, "The Spouter-Inn," a literature podcast and forum to talk, laugh, think, and wonder, which airs on www.megaphonic.fm/spouter.

Akbari earned a B.A. from Johns Hopkins University in 1984. She went on to study at Columbia University, earning an M.A. in English (1989) and an M.Phil. and Ph.D. in English and Comparative Literature (1991 and 1995). She has received numerous grants in support of her work, including an award from the Andrew W. Mellon Foundation, the Insight Grant from the Social Sciences and Humanities Research Council of Canada, and the Chancellor Jackman Research Fellowship in the Humanities.

She is a Member of various professional societies including the Medieval Academy of America, BABEL Working Group, Modern Language Association, Canadian Society of Medievalists, American Comparative Literature Association, and the New Chaucer Society. ■

€10 Million ERC Synergy Grant Awarded for Study of Medieval Populations

IAS's Patrick Geary among four principal investigators to head study

The Institute for Advanced Study and its international partners have received a €10 million Synergy Grant from the European Research Council (ERC) to fund a multidisciplinary study of more than one hundred medieval cemeteries located across central and eastern Europe. The project, HistoGenes, will seek to understand the impact of migrations and mobility on the population of the Carpathian Basin from 400–900 C.E., based on a comprehensive analysis of samples from 6,000 ancient burial sites. HistoGenes will, for the first time, unite historians, archaeologists, geneticists, anthropologists, and specialists in bioinformatics, isotope analysis, and other scientific methods in understanding this key period of European history.

"I am extremely gratified by the confidence that the European Research Council has shown in my colleagues and myself in awarding us this grant. The size of the grant will make possible an extraordinary advance in both our understanding of Europe's population during a crucial historical period as well as in developing new procedures to integrate natural scientific and humanistic scholarship in a common effort," said Patrick Geary, Professor Emeritus in the School of Historical Studies, who is one of the project's four principal investigators. "The early support for our pilot project, provided by the IAS, was crucial in demonstrating the feasibility of these new approaches, and thus paved the way for this award."

In addition to Geary, the other principal investigators are Johannes Krause (Max Planck Institute for the Science of Human History, Jena, Germany), Walter Pohl (Austrian Academy of Sciences, Vienna, Austria), and Tivadar Vida (Eötvös Loránd University, Budapest, Hungary). In the United States, the research team includes Professor Krishna Veeramah, a population geneticist from Stony Brook University. Geary and Veeramah had previously led a pilot study, published in *Nature Communications* in 2018, which sequenced the genomes of entire ancient cemeteries to examine the relationship between the genetic background of these communities and the archaeological material left behind.

The core objectives of the project are to explore the impact of mobility on early medieval populations, refine the methods of archaeogenetic research, and establish a multidisciplinary model for future research. ■

Seventy Years and Two Paradigm Shifts: The Changing Faces of Biology

What does one learn from all this reductionism without the organism?

BY ARNOLD J. LEVINE

In the summer of 1968, a young, newly minted assistant professor moved from a postdoctoral position at Caltech to Princeton University. Schooled and trained over the previous seven years in the reductionist approaches of Watson and Cricks' molecular biology, he moved into the Moffett Laboratory to study how the simplest of organisms, a virus, could cause cancer in a mouse or in a hamster. Among the questions under study in the laboratory were: how many genes did the virus devote to causing cancer? How did the proteins encoded by these genes function to initiate and to maintain a tumor? What were the molecular mechanisms involved? The Moffett laboratory building was a newer extension to Guyot Hall, which had been built in 1909 for the Geology and (then) newly created Biology Department.

A great deal of the space at the entrance of the building was taken up with stuffed animals, jars filled with formalin containing suspended embryos, skeletons of animals that no longer exist, and plants imprinted into rocks millions of years ago. Plates that Audubon used to etch images of his birds and print his beautiful books hung on the walls. The diversity and varieties of animals selected by Darwinian evolution over the geological ages were in evidence, extolling the unity of all organisms and the central tenets of geology and biology. It was a great biological museum, dedicated to a biology that began in 1859, when Darwin published his book *On the Origin of Species*, and stretched to 1953, when Watson and Crick published a paper on the structure of DNA. From 1953 to 1968, a generation of young biologists were passing through Thomas Kuhn's paradigm shift from organismic biology, celebrated in the Guyot museum, to molecular biology, viewing life at the molecular level and asking questions that often ignored the organism, its natural life cycle, and its interactions with the environment. The new molecular biologists would look forward to the sequences of those chemicals that made up DNA as the proper study of evolution.

Arnold Levine (center), Professor Emeritus in the School of Natural Sciences, established the Institute's Simons Center for Systems Biology, which conducts research at the interface of molecular biology and the physical sciences by theoretical physicists, cancer biologists, mathematicians, and computational biologists.

Watson and Crick (1953) built a model of DNA using Rosalind Franklin's X-ray data and Erwin Chargaff's rules. That model made two clear predictions: The double helix would replicate in a semi-conservative fashion, separating the two parental strands of DNA, which could then act as templates using base pairing. This was demonstrated to be the case in 1958 (Meselson and Stahl). Second, the sequence of nucleotides (the basic building blocks of DNA and RNA, consisting of a nitrogenous base, a five-carbon sugar, and at least one phosphate group) in the DNA polymer contained information, a genetic code, determining the sequences of amino acids in proteins and, eventually, the structure and the function of the protein. The first codon (UUU=phenylalanine) was elucidated in 1961 (Nirenberg and Matthaei). The founders of molecular biology employed the simplest of organisms: bacteria and their viruses, using the tools of genetics, models of molecular circuits in a cell, and they invented new methods that were required to explore DNA, RNA, and proteins at the molecular level.

This paradigm shift came with many levels of change. The molecular biologists were often blue-collar workers, toiling in the laboratory day and night seven days a week. Pipetting was repetitive and experiments were hard and didn't work unless you got it right. And if it was right, it had to be reproducible every time. The first molecular biologists to arrive at Princeton (1965–75) trained at Stanford, Berkeley, the Pasteur Institute, Geneva, Cambridge (England), and Caltech rather than the Ivy League Schools that produced many of the senior professors in the department. They liked Bob Dylan and rock music and hated the Vietnam war, rebelling against their countries' decisions, voting to bring women into the Ivy League Schools (Princeton accepted female undergraduates in 1969), and taking time to listen to the few black students at the University discuss issues of equality.

The molecular biologists liked the June through September break in the school year, and they stayed in the laboratory or attended meetings at Cold Spring Harbor. Most senior faculty spent the summer at Woods Hole, while others wrote books in secluded summer homes. There was a whiff of arrogance about the molecular biologists. They were convinced that they would change our understanding of life and life processes, and thereby change the world. They were not all wrong.

By the 1970s, genes were cloned and isolated and the sequences of the nucleotides revealed the proteins that they made, which could then be expressed and produced in bacteria. Change was coming rapidly but not without fear and objections and hotly contested questioning about the safety of moving genes around into new species. A common question was "What does one learn from all this reductionism without the organism?" Jacques Monod's answer was "What is true for *E. coli* is true for the elephant." The response referred to the parable of a blind man examining an elephant: you study the tail or the trunk and that is all there is and that is all you know. There was a tension about what biology departments of the future would look like. What were the right subjects to teach the next generation? And what approach to biology would be given the space and the money to take the future?

These questions were played out in interesting and often complicated ways. In biology and biochemistry at Princeton, the first-year graduate students met in a class setting to discuss how a researcher chooses his or her research problem to start a laboratory. This discussion was a way to introduce each faculty member to the first-year class, discuss the science carried out by the faculty, and have lots of time to explore how and why the faculty decide the paths of their research questions. The class was held in the evening, and two faulty members were paired so that the students would hear two points of view and diverse ideas.

One year, I was paired with the Chairman of the Biology Department, John Tyler Bonner. John was a gifted scientist and a true gentleman, the kind of chairman everyone respected. He had attended Harvard University for his studies, working on the biology of the cellular slime mold, *Dictyostelium discoideum*. In solving his thesis problem on this slime mold, he had made a real breakthrough, demonstrating that an important part of the life cycle of *Dictyostelium discoideum* employed a chemotactic factor to create a fused multicellular structure from single cell amoeba. At Princeton, John had demonstrated that the chemical signal that initiates aggregation of cells was cyclic AMP. These organisms are at the evolutionary transition of single cells to multicellular organisms.

On the evening of our discussion with the graduate students, John spoke first, telling the students how and why he had worked his entire career on this slime mold. He started by outlining the life cycle of this mold. A large number of single cell amoeba in a pond or in a petri dish (in the lab) swim and crawl around eating bacteria, which serves as their food source. They can reproduce asexually as amoeba. When they run out of bacteria, a chemotactic signal begins in some amoeba that attracts other amoeba, fusing into a giant zygote cell. The fusion of lots of amoeba initiates a sexual cycle (these molds have three sexes), and the macrocyst that forms diploid nuclei undergoes meiosis, which is followed by mitosis. As bacteria repopulate the environment, haploid amoeba are released from the macrocyst to feed and reproduce asexually, beginning the next life cycle. John stressed that he was intrigued by the events and complexity of the life cycle and its interaction with environmental clues for development. He pointed out that he had worked on this organism as an undergraduate, graduate student, and faculty member, all his scientific life, and would continue doing so because many questions remained to be studied. It was clear from his description of these events that he was deeply committed to this work and this organism. It was a compelling presentation.

It was now my turn to present the research questions my laboratory investigated. I started by pointing out that even as a high school student I was fascinated by viruses; they were so simple. The virus I worked with at Princeton had only six genes, yet it had a program to replicate itself in a cell, by borrowing some cellular functions. What were the functions of the viral and cellular genes that had this ability to duplicate themselves by taking over the cell? But more, when this virus was injected into newborn hamsters, it often caused a cancer to grow some six to nine months later. Every cancer cell had a copy of the viral DNA integrated into a cellular chromosome, and that integrated viral DNA expressed a subset of the virus-encoded proteins. I wanted to figure out what genes and their proteins replicated this virus, and what genes and their proteins caused the cancer, and how they functioned to make a tumor. And when I figured this out, I would move on to another organism and another research problem.

I think both John and I were aware of the differences in our philosophies of doing research, and that we were what we were and could not be anything else. But it was good for the students to be exposed to different ideas, approaches, and levels of analysis. Although my exposure and training were all at the molecular level, it was good for me, as a research scientist, to be exposed to organismic biology, evolutionary biology, and ecology. I am not so sure it was as easy to be a senior chairman and professor when young researchers with all the answers came

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BIOLOGY *(Continued from page 8)*

to town. To quote John, from his book *Biology at Princeton (1947–2012)*, a history of the department, from a chapter called "The Molecular Wars" he notes that the opinions of molecular biologists were "all of biology must now be subsumed under molecular biology. All of the people working on any other form of biology were barking up the wrong tree; that tree was all dead wood." Princeton, of course, was not the only University to live through these times of change, and most schools, like Princeton, solved the problem by forming two departments of biology, one called "Ecology and Evolution" and the other "Molecular Biology." Today both departments contribute and flourish.

Ironically, that is not the end of this story. As the last thirty years of the twentieth century progressed, new technologies were developed that permitted examination of the transcription levels of thousands of genes in a group of cells and all the transcripts in a single cell. The sequencing of larger genomes culminated in the sequence of the human genome in 2001. Today, we do study evolution by sequencing and studying thousands of genomes from different organisms. We follow the relationships and evolutionary changes of genes over time and in novel organisms; we construct new trees of life forms; and we observe new processes of evolutionary change. DNA contains many diverse types of information that we need to understand.

DAN KOMODA

Former IAS Member Raúl Rabadán gives the talk "Some Quantitative Problems in Evolution and Heterogeneity of Human Cancers" at the 2019 Prospects in Theoretical Physics program "Great Problems in Biology for Physicists." View videos at www.ias.edu/ideas/videos-pitp-2019.

A deeper explanation of how genotypes are translated into phenotypes has begun. The exploration of how gene functions, organisms, and populations respond to a changing environment over a billion years is under study. We have explored the origins of humans in Africa, their migrations and formation of racial groups over hundreds of thousands of years. We study epidemics and pandemics by sequencing infectious agents over time scales of hundreds of years. The study of viruses that cause cancer in animals has led to the discovery of oncogenes and tumor suppressor genes that cause cancers in humans. Many investigators have now stopped their studies with viruses and instead focused on the gene functions and the mutations that cause human cancers. Cancer, like evolution, presents us with combinatorial changes of genes in a genome. We have assembled vast datasets of information and need to extract meaning from them. We now find that the average molecular biologist does not have the quantitative skills to handle these large datasets, extract information from them, and translate that information into the behavior and form of the organism. The study of life is becoming the elucidation of information storage and organization, information read out, stability and repair, and the selective use of information in response to reproductive requirements, nutrient use, and environmental stresses.

The current paradigm shift is back to integrative or systems biology, which is being populated by individuals trained in physics, computer sciences, mathematics, and engineering, who learn biology and work with biologists who can test their ideas in a laboratory or even the clinic. This process of collaborative science, termed "convergence" by Phil Sharp, is starting to populate universities, medical schools, and research institutes.

Topological applications are being applied to datasets to classify the shapes of information that populate different datasets. Information theory is being applied to signal transduction (the process by which a chemical or physical signal is transmitted through a cell as a series of molecular events, *e.g. protein phosphorylation resulting in a cellular response*) so as to determine which genes contain the maximum entropy (a measure of the information, or connections) in a cellular network. Neural networks are being designed for biological questions and to permit machine learning to explore associations and patterns not previously identified. Machine learning is creating new technologies that will change how we do biology. There are undergraduate and graduate programs in biology that are demanding quantitative skills in mathematics or computer science not practiced at present in the field of molecular biology. Scientists trained in physics or computer science are taking postdoctoral positions to learn biology and apply their skills to biological questions. Time will tell what the impact of these fusions of disciplines will lead to and the directions to be taken by biological questions.

Throughout the twentieth century physicists and mathematicians have come into biology, and some have made a considerable impact. Mostly, this pattern of convergence has not persisted. Will it be different this time? Will it become a branch of biology? Will systems biology replace molecular biology as the most common approach to biological questions? The questions to be explored are now extraordinary and the depth of information to explore them has never been greater, so the attraction of young scientists to the biological sciences is clear. The very tools created by the molecular biologists of the late twentieth and early twenty-first centuries have sparked a revolution of biological information that now needs to be analyzed and understood. This will require a new skill set. The tools of biology will blend with computer sciences, physics, and mathematics, and the practitioners of biology will undergo another paradigm shift.

To have lived through one paradigm shift in biology is demanding; to go through two such changes is a testament to the progress that science is making and the pace of change. ■

Arnold Levine, Professor Emeritus in the School of Natural Sciences, was appointed to the Faculty in 2004. At IAS, he established the Simons Center for Systems Biology, which conducts research at the interface of molecular biology and the physical sciences by theoretical physicists, cancer biologists, mathematicians, and computational biologists.

Levine was among the first researchers to independently isolate the p53 protein in 1979. The discovery of p53 generated approximately 50,000 papers within the first thirty years. In a 1991 Nature *paper, Levine and his collaborators reported that mutation of the p53 gene is the single most common genetic alteration observed in human cancers. Researchers have identified p53 mutations in 100 percent of ovarian cancers, 70–90 percent of lung and colon cancers, and up to 33 percent of breast tumors.*

During his career, Levine has worked across the biological sciences, from virology and immunology to molecular biology and genetics, and mentored countless scholars. In September, the Institute hosted two days of talks in celebration of his eightieth birthday and the fortieth anniversary of p53. Videos are available at www.ias.edu/ideas/videos-levine-eightieth.

TSODYKS *(Continued from page 1)*

Systems Biology while forging connections throughout the Institute and sustaining his fruitful collaborations with the Weizmann Institute."

Recognized by theorists and experimentalists alike for his original thinking, Tsodyks has developed concepts that have influenced several important areas of neurobiology. Among his principal achievements are his description and interpretation of short-term synaptic plasticity; solving a highly influential model of associative memory; enhancing understanding of how inhibition plays a stabilizing role in neural circuits; and addressing the paradox between the large capacity of human long-term memory and its limited recall ability. He has also helped researchers better understand various phenomena connected with higher cognitive functions, such as storage and retrieval of working memories in cortical systems, as well as the coding and retrieval of spatial information within the hippocampus during navigation.

"I am delighted that Misha Tsodyks will join our theoretical biology community at the Institute. His approach, based in the tradition of theoretical physics and solidly anchored in experimental neurobiology, has led him already to many interesting results," said Stanislas Leibler, Professor in the School of Natural Sciences. "I hope that the academic environment of the Institute will allow him to pursue further his quest for better understanding of human cognition."

Working with large amounts of data, Tsodyks formulates problems in quantitative terms, achieving a unique blend of mathematical beauty and biological relevance. A prolific collaborator, his work is also marked by a rare balance between theoretical and practical concerns, repeatedly devising elegant conceptual models in a range of different topics that make quantitative testable predictions for experiments. Tsodyks's physical approach to modeling is particularly compelling, echoing the work of John Hopfield, neural network pioneer and former Institute Visiting Professor, who remains active within the Simons Center for Systems Biology.

"I am very happy and grateful for the opportunity to join the IAS and benefit from its fantastic intellectual environment," remarked Tsodyks.

Tsodyks received his Ph.D. in 1987 from the L.D. Landau Institute for Theoretical Physics in Moscow and earned his M.Sc. from the Moscow Physical-Technical Institute in 1983. Tsodyks has been at the Weizmann Institute of Science since 1995 and was promoted to full Professor in 2005. Since 2010, he has also been associated with Columbia University, first as an Adjunct Professor and then, since 2015, as a Visiting Professor. He is the recipient of various fellowships and a 2017 winner of the Mathematical Neuroscience Prize from Israel Brain Technologies.

The C.V. Starr Professorship is endowed by a generous grant from the Starr Foundation. ■

The Social Life of DNA

Race, reparations, and reconciliation after the genome

BY ALONDRA NELSON

Like many Americans, my family and I were riveted by the *Roots* miniseries when it first aired in January 1977. I vividly recall sitting in front of the television with my mother, father, sister, and two brothers, watching the story of Alex Haley's family unfold in Technicolor.

My father, having just completed a tour at sea, reclined in an armchair, his feet up. My mother was on the sofa with one or two of us kids twined tightly around her. The other two of us were on the floor, alternately being admonished by our parents not to lie too close to the screen or told, courtesy of a sibling, to move out of the way. On Sunday evening, when it became apparent that we would view the first episode in its entirety—well past our bedtimes—we knew we were in uncharted territory.

DAN KOMODA

Above (top): Alondra Nelson, who joined the School of Social Science as Harold F. Linder Professor in July; (bottom) as a cheerleader (far right) in Southern California in the late 1970s

The *Roots* occasion provided one of those unforgettable moments when a child sees her parents in a new light. Watching *Roots*, I also watched my parents, who were visibly stirred by Haley's account. More than a few times during those eight evenings, my mother's eyes welled with tears. She frequently shook her head and murmured "Uhm-uhmuhm," as I had heard Mary, her Philadelphia-born mother, do many times. An inherited response for emotions that defy language, perhaps. My father, who hailed from New Orleans, was characteristically stoic, but occasionally allowed a "That's a damn shame" during an especially graphic or tragic scene. I realize now that while watching *Roots*, my parents similarly watched us, their children. They were worried and protective, interspersing their own commentary between scenes, hoping to ameliorate the dramatic effect of this painful history.

The *Roots* effect expanded beyond our family home, perched on the edge of a craggy San Diego canyon, to my grade school, nestled in a valley. I was called Kizzy and Kunta Kinte by my mostly blond classmates during first period at my Southern California private school. But during our lunch breaks, the teasing gave way to earnest but clumsy conversations. In the schoolyard, we tried to make sense of what *Roots* meant for our interracial friendships, for our discussions in Sister Nora's American history class, and for our nation in the wake of its bicentennial. In our own ways, we each wondered: Who are we in relation to this history? Did this really happen? If so, how did we get from then to now—and where do we go from here?

Haley made his mark as a collaborator on *The Autobiography of Malcolm X*, the late activist's influential account of his political transformation published in 1965. This work emerged at the beginning of the black power era. *Roots*, published in 1976, and the television miniseries that was based on it, which premiered a year later, were culminating symbols of the era. This was the time of the Afro and the dashiki—of the "Black is beautiful" ethos. Between 1965 and 1977, black Americans turned to their African origins with intensity.

DNA IS THE ULTIMATE BIG DATA. GENETIC DATA IS MULTIVOCAL AND CONTAINS INFORMATION THAT CAN BE USED IN VARIED FACETS OF SOCIETY REGARDLESS OF ITS SOURCE OR ITS ORIGINAL INTENT OF USE.

This interest in African origins and, in turn, genealogy, was piqued in 1977. This watershed year also saw the publication of *Black Genealogy* by Charles L. Blockson, a primer of root-seeking attuned to the needs of African Americans, who faced especially steep hurdles in tracing ancestry. The Afro-American Historical and Genealogical Society (AAHGS), the first national black organization dedicated to genealogy and family history, was also established in 1977. In the intervening decades, genealogy only grew in appeal for African Americans. In the last decade, with the decoding of the human genome, new tools were introduced that expanded the popularity of genealogy exponentially and, moreover, gave it multifaceted uses.

I began research for *The Social Life of DNA* in 2003 after noting mention in the press of a DNA testing service that promised to help blacks trace their roots. I was captivated. At that time, genetic ancestry testing was in its infancy and traditional gatherings of genealogists were where the early adopters of these new root-seeking techniques could be found. I attended scores of these gatherings, large and small, throughout the country, from Oakland, California, to Bedford, Massachusetts, and numerous places in between. My travels also took me to the United Kingdom. In these places, I encountered genealogists who had been using archives and oral history to reconstruct their family stories and who were willing to try the new genetic-ancestry-testing services that were just hitting the market.

I've also participated in events and conferences at which genetic genealogy testing was discussed, including meetings at churches, libraries, and universities, and conducted fieldwork and interviews in settings both virtual and concrete. I interacted with genetic genealogists and eventually, in a now well-established tradition of social science research called "participant observation," I also became a root-seeker. I started conducting research on my own family's history, which besides Pennsylvania and Louisiana traverses parts of the southern United States as well as the country of Jamaica, and became a card-carrying member of the Afro-American Historical and Genealogical Society.

Building a bridge to Africa has inspired black American arts, letters, and politics for generations. Even if these speculative "roots" tests I read about never materialized, here a cutting-edge answer was being proposed to a central enigma of African America—a remedy that seemed ripped from the pages of a sci-fi novel. Speculation soon gave way to the news that a black geneticist named Rick A. Kittles had launched African Ancestry with his business partner, Gina Paige. Among the earliest direct-to-consumer testing companies in the United States, it was the first niche-marketed to people of African descent. As an ethnographer and historian of African America, with a special interest in science and technology—as befitting a child born from the union of a cryptographer and a mechanical technician—I knew that I had to join Kittles on this journey.

I used what social scientists call "snowball sampling" when conducting my interviews with root-seekers. In other words, I interviewed genealogists about their decision to use genetic ancestry testing and the effects of the results on their lives, and they, in turn, referred me to others. As I would discover, what was snowballing was not only the number of people in my interview network, but the surprising ways the test results were being put to use. That is, I was also being given an unexpected map of how genetic information was being used by individuals, communities, and institutions. Yes, personal and family information was gleaned. But in these conversations, there was also growing mention of how broadly genetic ancestry testing was being used as the industry evolved. For over a decade, I've followed Kittles and African Ancestry, and in this time, have come to take a long view of genetic ancestry testing, a perspective that is more mosaic than the predictable, ritualized scenes of revelation and surprise we have become accustomed to witnessing on popular genealogy television shows.

As a wide-eyed girl watching *Roots*, and wondering about mine, I never could have dreamed a future where one day I'd have the surreal experience of having my genealogical results revealed to me before a crowd of African diaspora VIPs and civil rights leaders, and with a prominent actor, Isaiah Washington, as master of ceremonies. Although this experience elicited mixed emotions in me, I can personally attest that new branches on ancestral trees are the undeniable graft of genetic genealogy.

The Social Life of DNA unearths what else we try to accomplish with these tests, including political and legal uses. I've found this might include establishing ties with African ancestral homelands, transforming citizenship, recasting history, or making the case for reparations which, as we know, is an issue that is once again part of our national conversation. I describe these lesser-known but truly momentous uses of genetic ancestry testing as "reconciliation projects," endeavors in which genetic analysis is placed at the center of social unification efforts. These may be legal attempts to financially reconcile formerly opposed parties like the descendants of enslaved persons and the current-day companies that profited from

(Continued on page 11)

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slavery, such as Aetna, JP Morgan Chase, and Wachovia. Reconciliation projects are also efforts to reunite formerly unified parties like blacks in the United States seeking to reconnect with lost kin and community in Africa. They may also be used to reestablish biographical or historical information that has been lost to the march of time or to settle contentious issues. In short, these DNA-based techniques are offering a new tool to examine long-standing issues, and these reconciliation projects reveal manifold and potentially transformative possibilities.

The Social Life of DNA tells the compelling, unexpected, and still-unfolding story of how genetics came to rest at the center of our collective conversation about the troubled history of race in America. I hope you will join me on this foray into an extraordinary, uncharted arena of twenty-first-century racial politics.

The summer of 2010 marked the tenth anniversary of the decoding of the "first draft" of the human genome. This scientific milestone was met with cautious appraisal from

Photo taken by Alondra Nelson during her "snowball sampling" interviews with root-seekers.

usually enthusiastic quarters. Leading science reporter Nicholas Wade bemoaned in the *New York Times* that "after 10 years of effort" the therapeutic promise of genomics "remains largely elusive." J. Craig Venter, the maverick geneticist who was a major force behind the Human Genome Project, declared more emphatically in *Der Spiegel* that "we have learned nothing from the genome." These sober assessments were surprising given how profoundly our social world has been changed by genetic science and its applications in the last decade.

While concrete health benefits stemming from the Human Genome Project may indeed be "elusive," its broader impacts are clear. Genetic analysis has become widespread. There is no question that genetics research is prevalent in biomedicine, even if its ability to predict or remedy ills remains to be fully demonstrated. In criminal justice settings, DNA is becoming ubiquitous and is double-edged, playing a role in both conviction and exoneration. And commercially available genetic tests that claim to specify genealogy, ancestral affiliation, or racial and ethnic identity are among the most conspicuous signposts of our genome age. In these different institutional settings, we have zealously (and often uncritically) seized upon DNA as a master key that unlocks many secrets.

DNA is the ultimate big data. Genetic data is multivocal and contains information that can be used in varied facets of society regardless of its source or its original intent of use. And genes are omnibus; they confer many types of information simultaneously. DNA analysis therefore moves across and between the expected medical, forensic, and genealogical domains, and also beyond them into a wider set of arenas, with expanded purpose. Diverse ends and aspirations are now sought with and through the use of genetics. This diffusion comprises the social life of DNA.

This social-life approach to genetics follows the methodology of the anthropologist Arjun Appadurai, who, in *The Social Life of Things*, argues that to understand what objects mean and why they are important we must trace their circulation in society ("things-in-motion"), illuminating "their human and social context" and revealing "the human transactions and calculations that enliven things." By similarly tracking DNA analysis, we gain insight into where and why genetics is called upon to answer fundamental questions about human existence, often through extensions of its popular genealogical uses. Genetics is today engaged in practices of identity formation, in philanthropy and socioeconomic development projects, as corroborating evidence in civil litigation and historical debates, and elsewhere. Thus, although the therapeutic utility of the genome may be arguable, the social life of DNA is unmistakable: the double helix now lies at the center of some of the most significant issues of our time.

In light of African Ancestry's burgeoning business, what does the use of genetics in the context of long-standing cultural aspirations and political struggles suggest about the prospects for racial reconciliation in the United States? Activist groups and NGOs—including some, like the Leon Sullivan Foundation, with direct ties to the late-twentieth-century civil rights movement, and others, like the Descendants of the African Burial Ground, that carry the march toward racial justice forward into the twenty-first century—are turning to genetics to accomplish goals formerly pursued through grassroots organizing, electoral politics, and moral suasion. Laments about the decline of the civil rights activist tradition may thus be misplaced. Activism is simply taking new forms, in line with the scientific and technological innovations of the last decade, as the social media campaigns that sparked national protests against police brutality in Jena, Louisiana; Ferguson, Missouri; Baltimore, Maryland; and at other sites in recent years make clear. And given cautionary observations about the lack of participation of minorities in science and technology and these same communities' traditional (and well-founded) mistrust of these and related fields, the embrace of genetics for liberatory ends is particularly striking.

However, efforts to reclaim original identity through genetic technologies, while psychically beneficial, fail to materially address persistent structural inequality. In the same way that the scientific and therapeutic applications of DNA research may not yet have fully lived up to expectations, the application of genetic technologies to reconciliation initiatives brings their technical, institutional, and political limits into stark relief. The trajectory of the reconciliation projects discussed in *The Social Life of DNA* suggests that ultimately, equality, justice, and ethics are not easily tethered to or readily settled with DNA evidence.

We should worry that, with their reliance on commercial products, well-intentioned, innovative uses of genetic genealogy might contribute to a world in which claims for citizenship are tied to practices of consumption. And we should worry mightily about the transposition of the principles of justice into scientific techniques. But we should also appreciate that these endeavors are an innovative strategy on the part of some who find other avenues to historical awareness and social justice blocked, and who pursue the road to racial reconciliation nevertheless. ■

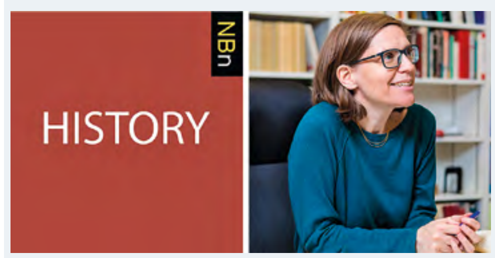
Alondra Nelson, who joined the Institute's School of Social Science as Harold F. Linder Professor in July 2019, is an acclaimed sociologist who explores questions in science, technology, and social inequality. Nelson's major research contributions are situated at the intersection of racial formation and social citizenship, and emerging scientific and technological phenomena. This article is a slightly edited excerpt from Alondra Nelson's The Social Promise of DNA: Race, Reparations, and Reconciliation After the Genome *(Beacon Press, 2016).*

Talking Points

On reparations, democracy, and market forces

Who should receive reparations for slavery and discrimination? Alondra Nelson, Harold F. Linder Professor in the School of Social Science, joins Joshua Rothman and prominent scholars Darrick Hamilton and William A. Darity to discuss reparations—how they would work, and who would be eligible. *—The New Yorker Radio Hour, May 28, 2019, www.ias.edu/nelson-podcast*

Why did democracy begin in Athens? What was it like when it first emerged? Angelos Chaniotis, Professor in the School of Historical Studies, discusses the origins of democracy with Andrew Keen and finds clues to preserving the modern version. *—How to Fix Democracy, May 15, 2019, www.ias.edu/chaniotis-podcast*



"What these [medieval] moral theologians were grappling with is something with which we are still grappling in many ways, that is, how to support the expansion of market forces, including financial instruments that have the potential of benefiting the state and society at large, and at the same time curb the excess of the market and finance." Francesca Trivellato, Andrew W. Mellon Professor in the School of Historical Studies, discusses her book *The Promise and Peril of Credit.—New Books in History, June 7, 2019, www.ias.edu/trivellato-podcast*

Political Action: A Practical Guide to Movement Politics

Get together, knock on doors, talk and listen to your neighbors

BY MICHAEL WALZER

Originally published in 1971, Political Action: A Practical Guide to Movement Politics *by Michael Walzer, Professor Emeritus in the Institute's School of Social Science, was republished by* New York Review of Books *in 2019. The following is Walzer's preface to the new edition.*

Written almost fifty years ago, in the immediate aftermath of the American bombing of Cambodia, *Political Action: A Practical Guide to Movement Politics* reflects a decade of intense political activity. Since I was aiming at a guide that would be helpful to citizen activists of all sorts, I avoided specific references to sixties politics; I wrote in a generalizing mode. But now I want to describe to new readers some of the concrete engagements that made me a citizen activist and led me to write *Political Action*.

Movement politics is mostly the work of the young, and I was very young, twenty-five, an unhappy graduate student, when Irving Howe, the editor of *Dissent*, asked me to fly to North Carolina and talk to and write about the black college students who were sitting in at Woolworth lunch counters. It was February 1960, and the sit-ins were the beginning of The Sixties.

I did talk to the students and write about them, but what was more important, I helped organize, with other liberals and leftists in the Boston area, the Emergency Public Integration Committee (EPIC), whose members picketed local Woolworth stores in solidarity with the Southern sit-inners. EPIC started with a good name, which is important, and at its peak was running demonstrations in front of some forty stores in and around Boston. A friend and fellow graduate student was the organizing genius behind all this; I mostly talked, explained what we were doing, recruited picketers at the region's many universities—and struggled to ward off ideologues on the farther left, who wanted EPIC to make a revolution. I also consulted with lawyers and, together with the picket-line captains, negotiated with the police, who were mostly unfriendly but careful and correct, and who didn't harass the picketers so long as we didn't harass the shoppers.

BETTMANN/GETTY IMAGES

On February 13, 1960, students line the counter of a dime store in Greensboro, North Carolina, in protest of the store's refusal to serve them.

Ours was a single-issue politics. We knew that racism in the United States reached far beyond whites-only lunch counters, segregated restrooms, and back-of-the-bus seating, but we followed the students in the South; we were not an independent movement. EPIC had a short life; after 1960, Northern supporters of the civil rights movement went South, marched in Alabama rather than in Boston. And of course we marched in Washington, too, and listened, standing there or on the radio, to Martin Luther King Jr.'s famous "I Have a Dream" speech. But it might have been more effective in the long run had we sustained local organizations in the North where racism was less visible, perhaps, but a powerful force nonetheless. So I began to think about how activists, such as we were, could keep things going.

A large number of civil rights activists moved naturally into the anti-Vietnam War movement. That was my next political destination and, again, my most intense engagement was local. By the mid-sixties, we had a new model for local political action: Students for a Democratic Society (SDS) community organizing. In 1967, I joined with a few people from Harvard SDS to organize the Cambridge Neighborhood Committee on Vietnam (CNCV), whose aim was to mobilize the city of Cambridge against the war. We went house to house, block by block, talking to whoever would talk to us, looking for someone who would volunteer to host a neighborhood meeting where we could defend the antiwar position.

Community organizing, SDS-style, required us to find "community people" and make them the leaders of the organization. This could be an inauthentic politics, where the young activists sat in the back of the room while a community person ran the meeting, and the people attending got cricks in their necks looking back for cues from the real leaders. But that wasn't the case in CNCV. One of our early volunteers was a part-time film editor and young mother who turned out to understand more about organizing than any of the rest of us—and who went from the CNCV to law school and a distinguished career in civil liberties work. I was her co-chair, who talked, probably too much, at our frequent meetings and fended off the Trotskyists.

Every organization needs a project; activists can't just talk; they have to find something to do. So we circulated petitions to put a statement on the November ballot calling on the city of Cambridge to hold a one-day rally against the war. With the help of a friendly lawyer, we got on the ballot, and then went door to door asking for votes. Looking for help, we gathered our courage and invited King to come to Cambridge and knock on a door. He came and knocked in front of reporters and cameras, and briefly we brought the civil rights and antiwar movements together (but only a few of the black preachers followed King's lead).

I doubt that King helped us in the white ethnic neighborhoods of Cambridge. We got 40 percent of the vote in November, and lost every working-class district. Only Harvard Square and its immediate surround voted strongly against the war. We recruited a few community people but hardly made a dent in the larger community. Still, CNCV had established a presence in at least part of Cambridge and might have survived as a political organization, reaching out to other issues and seeking a wider base (a few people suggested that we run a candidate for city council). But that was not to be.

Political activity requires a lot of work, and the distribution of the work is a central issue, not because activists try to avoid the burden but because they are too eager to embrace it. The younger activists, even if they are students or instructors (as I was) in supposedly demanding universities, have a lot of time for all sorts of organizational work and especially for meetings. The community people are older, with jobs and families; their time for political action is limited. So the young sit through long meetings, work long hours, and take over. But we were, most of us, without community roots and with very strong ideological commitments. As the war in Vietnam escalated, became morally unbearable, we started arguing among ourselves about what ought to be done. We had no particular interest in Cambridge city politics; indeed, the war made local politics look less and less important. We were drawn into national debates, and in these debates, we took different sides. So CNCV died of division.

Some of us went into draft resistance; a very few joined the Weathermen and tried "to bring the war home"; most of us supported the presidential campaign of Eugene McCarthy (as I did). I traveled briefly with McCarthy and made notes for some of his speeches (and he wrote a foreword for the original edition of this book). Not all citizen movements have to end with electoral politics, but I thought that was the right end for the antiwar movements of the late sixties. Our central obligation was simply to stop the war, as McCarthy would have done—and probably Robert Kennedy, too, who stepped in late in the day and added to the divisions on the left. His assassination led to Hubert Humphrey's nomination and then the disastrous defeat of 1968.

What followed was the invasion of Cambodia, ordered by Richard Nixon and Henry Kissinger—which produced another big Washington march but no renewal of local antiwar politics. The divisions on the political and intellectual left were deep and, so it seemed, irreconcilable. For the moment, I had nothing to do, and when political activists can't act, they write a book.

The editors at New York Review Books Classics have agreed to republish this book exactly as I wrote it in 1970–71, with all my incorrectly gendered pronouns. But I think that I was more aware than most sixties activists of the central role that women should play in our organizations. This isn't a period piece. Perhaps the only chapter that would need revision today is the one on the mass media, which deals with relations between activists and reporters. None of us anticipated the anarchy of the Internet, where thousands of people are posting and tweeting every day. What looks like participatory democracy has led, instead, to radical polarization and endless falsification. No doubt, the new media can help raise money and, maybe, get people to a demonstration; they can be used to spread the word about a new organizing effort—as in the aftermath of the shooting at Marjory Stoneman Douglas High School. But I don't believe

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Race After Technology: Shining Light on the New Jim Code

How biased are our algorithms?

BY RUHA BENJAMIN

I spent part of my childhood living with my grandma just off Crenshaw Boulevard in Los Angeles. My school was on the same street as our house, but I still spent many a day trying to coax kids on my block to "play school" with me on my grandma's huge concrete porch covered with that faux-grass carpet. For the few who would come, I would hand out little slips of paper and write math problems on a small chalkboard until someone would insist that we go play tag or hide-and-seek instead. Needless to say, I didn't have that many friends! But I still have fond memories of growing up off Crenshaw surrounded by people who took a genuine interest in one another's well-being and who, to this day, I can feel cheering me on as I continue to play school.

Some of my most vivid memories of growing up also involve the police. Looking out of the backseat window of the car as we passed the playground fence, boys lined up for police pat-downs; or hearing the nonstop rumble of police helicopters overhead, so close that the roof would shake while we all tried to ignore it. Business as usual. Later, as a young mom, anytime I went back to visit I would recall the frustration of trying to keep the kids asleep with the sound and light from the helicopter piercing the window's thin pane. Like everyone who lives in a heavily policed neighborhood, I grew up with a keen sense of being watched. Family, friends, and neighbors—all of us caught up in a carceral web, in which other people's safety and freedom are predicated on our containment.

Now, in the age of big data, many of us continue to be monitored and measured, but without the audible rumble of helicopters to which we can point. This doesn't mean we no longer feel what it's like to be a problem. We do. This book is my attempt to shine light in the other direction, to decode this subtle but no less hostile form of systemic bias, the New Jim Code.


DAN KOMODA

Member Ruha Benjamin (standing) gives the After Hours Conversation "Are Robots Racist?" while at IAS in 2016–17.

Engineered Inequality: Are Robots Racist?

WELCOME TO THE FIRST INTERNATIONAL BEAUTY CONTEST JUDGED BY ARTIFICIAL INTELLIGENCE.

So goes the cheery announcement for Beauty AI, an initiative developed by the Australian- and Hong Kong-based organization Youth Laboratories in conjunction with a number of companies who worked together to stage the first ever beauty contest judged by robots. The venture involved a few seemingly straightforward steps:

1. Contestants download the Beauty AI app.
2. Contestants make a selfie.
3. Robot jury examines all the photos.
4. Robot jury chooses a king and a queen.
5. News spreads around the world.

As for the rules, participants were not allowed to wear makeup or glasses or to don a beard. Robot judges were programmed to assess contestants on the basis of wrinkles, face symmetry, skin color, gender, age group, ethnicity, and "many other parameters." Over 6,000 submissions from approximately 100 countries poured in. *What could possibly go wrong?*

On August 2, 2016, the creators of Beauty AI expressed dismay at the fact that "the robots did not like people with dark skin." All 44 winners across the various age groups except six were White, and "only one finalist had visibly dark skin." The contest used what was considered at the time the most advanced machine-learning technology available. Called "deep learning," the software is trained to code beauty using pre-labeled images, then the images of contestants are judged against the algorithm's embedded preferences. Beauty, in short, is in the trained eye of the algorithm.

As one report about the contest put it, "[t]he simplest explanation for biased algorithms is that the humans who create them have their own deeply entrenched biases. That means that despite perceptions that algorithms are somehow neutral and uniquely objective, they can often reproduce and amplify existing prejudices." Columbia University professor Bernard Harcourt remarked: "The idea that you could come up with a culturally neutral, racially neutral conception of beauty is simply mindboggling." Beauty AI is a reminder, Harcourt notes, that humans are really doing the thinking, even when "we think it's neutral and scientific." And it is not just the human programmers' preference for Whiteness that is encoded, but the combined preferences of all the humans whose data are studied by machines as they learn to judge beauty and, as it turns out, health.

In addition to the skewed racial results, the framing of Beauty AI as a kind of preventative public health initiative raises the stakes considerably. The team of biogerontologists and data scientists working with Beauty AI explained that valuable information about people's health can be gleaned by "just processing their photos" and that, ultimately, the hope is to "find effective ways to slow down ageing and help people look healthy and beautiful." Given the overwhelming Whiteness of the winners and the conflation of socially biased notions of beauty and health, darker people are implicitly coded as unhealthy and unfit—assumptions that are at the heart of scientific racism and eugenic ideology and policies.

Deep learning is a subfield of machine learning in which "depth" refers to the layers of abstraction that a computer program makes, learning more "complicated concepts by building them out of simpler ones." With Beauty AI, deep learning was applied to image recognition; but it is also a method used for speech recognition, natural language processing, video game and board game programs, and even medical diagnosis. Social media filtering is the most common example of deep learning at work, as when Facebook auto-tags your photos with friends' names or apps that decide which news and advertisements to show you to increase the chances that you'll click. Within machine learning there is a distinction between "supervised" and "unsupervised" learning. Beauty AI was supervised, because the images used as training data were pre-labeled, whereas unsupervised deep learning uses data with very few labels. Mark Zuckerberg refers to deep learning as "the theory of the mind … How do we model—in machines—what human users are interested in and are going to do?" But the question for us is, is there only one theory of the mind, and whose mind is it modeled on? ■

Ruha Benjamin, Member (2016–17) in the School of Social Science, is Associate Professor in the Department of African American Studies at Princeton University where she studies the social dimensions of science, technology, and medicine, race and citizenship, knowledge and power. While at IAS in 2016–17, she gave the After Hours Conversation "Are Robots Racist?" which Benjamin describes in her book as "a ten-minute provocation [that] turned into a two-year project." This article is an excerpt from Benjamin's resulting book Race After Technology *(Polity, 2019). https://bit.ly/2Nxppjl*

WALZER *(Continued from page 12)*

that they can replace the face-to-face encounters that build and sustain movement politics. It is still necessary to get together in small groups, to argue at meetings, to knock on doors, to talk and to listen to your neighbors—which is what *Political Action* is about.

Every author dreams of a second life for his or her books, and I am grateful to be granted this one. Every political activist who has fought for a good cause dreams of a chance to fight again. We live, right now, in a bad time; American politics has not been this ugly since the Joe McCarthy years or the Red Scare and anti-immigrant frenzy of the early 1920s. We need movements of resistance, and we need citizen activists who remember the old labor union imperative: Organize! ■

Michael Walzer, appointed to the Faculty of the Institute's School of Social Science in 1980, is one of America's foremost political thinkers. He has written about a wide variety of topics in political theory and moral philosophy, including political obligation, just and unjust war, nationalism and ethnicity, economic justice, and the welfare state. Currently, he is working on issues having to do with international justice and the connection of religion and politics, and also on a collaborative project focused on the history of Jewish political thought.

The Spectre of Race

How discrimination haunts Western democracy

BY MICHAEL G. HANCHARD

As sociologists have reminded us, race, like power, is a relational concept. A so-called race is invariably defined in distinction to other presumed races. Where racial reasoning and the practice of comparison have combined in modern politics is in the rendering of judgments about the relative merits of groups of people distinguished by race, and subsequently, through the codification of categories and the attempt at regulation of populations, especially their interactions. In essence, apartheid and other forms of segregation can be boiled down to this more abstract formulation. Comparison, judgment, codification, hierarchy, and ultimately, inequality are the keywords that help characterize the process and relationship between the race construct, politics, and institutions in modernity.


ANDREA KANE

Member Michael G. Hanchard at a School of Social Science seminar in 2014–15

In a more dynamic understanding of the relationship between democratic and non-democratic institutions in societies with democratic polities, we can also explore how those excluded from citizenship in both ancient and modern eras sought and, in some cases, demanded participation in the democratic polities around them, or alternatively, sought to create polities of their own. Political and economic exclusion is often manifested in laws, norms, and coercive sanctions that delimited or outright prohibited noncitizen populations (slaves, women, serfs, and peasants among them) from participating in formal civic life. The combination of formal and informal institutions designed to limit political participation of the excluded can be conceptualized as mechanisms or institutions of political inequality.

POLITICAL AND ECONOMIC EXCLUSION IS OFTEN MANIFESTED IN LAWS, NORMS, AND COERCIVE SANCTIONS THAT DELIMITED OR OUTRIGHT PROHIBITED NONCITIZEN POPULATIONS (SLAVES, WOMEN, SERFS, AND PEASANTS AMONG THEM) FROM PARTICIPATING IN FORMAL CIVIC LIFE.

Most contemporary scholarship on inequality has focused on economic manifestations and disparities in life expectancy, health care, education, and stress-related diseases. Known as "the social question" in the eighteenth century in the aftermath of the French and U.S. revolutions, the roots of social inequality are often traced to the economic sphere. While not discounting the economic and material sources of social inequality, many aspects of social inequality have political roots. Gendered disparities are perhaps the most obvious manifestations of inequality. Neither the socially constituted character of gender roles, and certainly not nature, can explain why women, across the ages and spaces, have been subordinated in economic, social, and material relations. The ability to own property and access to wealth, education, and suffrage have their origins in law and custom that have privileged males in most societies.

Political and social inequality are often dynamically related, insofar as exclusionary and inclusionary criteria for citizenship formation and participation invariably emanate from the same source: state power. Yet one of the core lessons of *The Spectre of Race* is that political inequality is not simply an epiphenomenal feature of social and economic inequality. Instead, political inequality is often the result of deliberate decisions to exclude specific groups from participation in a polity and to deny their access to the same social and economic opportunities afforded to members of dominant groups. Whether by gender, social class, ethno-nationality, religion, or other forms of distinction, the administration and management of political inequality has varied by society and regime, and it has been based upon distinct criteria depending upon the marginalized groups in question and their demands for inclusion.

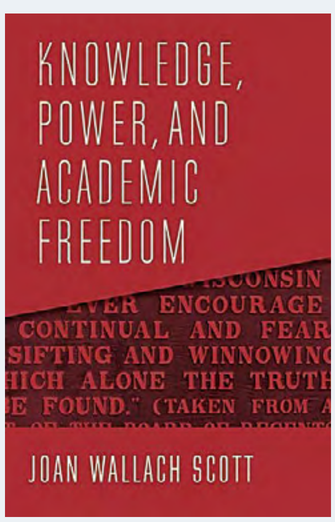
Racial, gendered, religious, and ethno-national chauvinism are among the forms of evaluative differentiation which, when embedded in political institutions, provide an interpretive means for governments to codify their preferences in law, edicts, and constitutions that then regulate people and their interactions. Moreover, these forms of differentiation, functioning as informal and formal institutions, have impacted the practice of democracy in three Western polities in particular: France, Britain, and the United States. Part of my contention in *The Spectre of Race* is that such forms of political inequality are not anomalous features of certain Western polities, but rather are the modern manifestations of the combination of democracy, difference, and inequality first invented and implemented in classical Athens. ■

Michael G. Hanchard, Member (2014–15) in the Institute's School of Social Science, is Professor and Chair of Africana Studies at the University of Pennsylvania. This article is excerpted from The Spectre of Race: How Discrimination Haunts Western Democracy, *which Hanchard worked on while at IAS. The book has been awarded the 2019 Ralph J. Bunche Award from the American Political Science Association and was named one of* Times Higher Education*'s Best Books of 2018. Copyright © 2018 by Michael G. Hanchard. Published by Princeton University Press. Reprinted by permission.*

Academic Freedom Under Fire

Preserving the integrity of scholarship and enabling dramatic expansion of legitimate knowledge

In my lifetime, academic freedom has been repeatedly under threat. In the 1950s, in the McCarthy era, hundreds of teachers were interrogated about their political beliefs and summarily fired, whether or not those beliefs had anything to do with the subject matter they taught. In the 1990s, "political correctness" was the term used by conservative critics of the university to attack the results of affirmative action and the subsequent increased diversity of students, faculty, and the curriculum. The first essay I wrote on the subject of academic freedom was for a series of lectures sponsored by the American Association of University Professors and subsequently published in 1996 in a book edited by Louis Menand. His introduction sought to reply to those who had denounced "multiculturalism" and "postmodernism" as philosophies that were antithetical to the truth-seeking project of the academy. He argued, as many of us did in our essays, that the presence of once-excluded groups in the university (women, African Americans, gays, and lesbians) required new forms of knowledge production; indeed, we pointed out that the supposed objectivity of an earlier curriculum was often a mask for entrenched patterns of discrimination. Challenges to disciplinary orthodoxies need not be violations of academic freedom, we insisted, but—when pursued with rigor and scholarly seriousness—were precisely exercises of that freedom. The success of the new programs, and their widespread adoption, is testimony to the ways in which academic freedom can at once preserve the integrity of scholarship and enable dramatic expansion of what counts as legitimate knowledge.

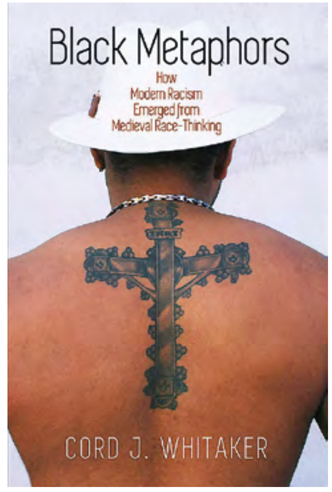


—*Joan Wallach Scott, Professor Emerita in the School of Social Science,* in Knowledge, Power, and Academic Freedom *(Columbia University Press, 2019)* ■

Black Metaphors in the *King of Tars*

How modern racism emerged from medieval race-thinking

BY CORD WHITAKER



In the late Middle Ages, Christian conversion could wash a black person's skin white—or at least that is what happens when a black sultan converts to Christianity in the late thirteenth- or early fourteenth-century English romance the *King of Tars*. The remarkable transformation, however, is not what it might at first appear to be. While some critics have taken the conversion as the conflation of racial and religious identity, the change is in fact not indicative of a cut-and-dried relationship between Christian identity and the normativity of European whiteness. The connection between color and religious identity in the late Middle Ages is rather more complex, and the *King of Tars* in particular exploits the normativity of physical whiteness in western Christendom when it advocates the necessity of metaphorical, or spiritual, "blackness" in Christians. In the *King of Tars*, the physical reality of skin color difference gives way to the metaphor of color that facilitates Christendom's necessary "blackness." Whiteness and blackness, in their material modes as well as their spiritual consequences or auras, cede primacy to one another continually, producing the shimmer of the black metaphor. The *King of Tars* didactically and rhetorically navigates the line between reality and metaphor in order to turn its reader's attention from the Christian mission to convert others, a defining feature of late medieval Crusades ideology, to the project of examining and maintaining her own spiritual well-being.

In order to consider how this process makes use of what I will call black metaphors—textual moments in which black skin signifies sameness and otherness, spiritual purity and sinfulness, salvation and damnation—I turn to what is perhaps the most powerful recent study of skin color as a metaphor—Toni Morrison's *Playing in the Dark*. Writing on the American and African American traditions, Morrison goes about proving the vast extent to which black figures are relevant in canonical American literature. Her insight into the didactic nature of race metaphors is as relevant to medieval literature as it is to modern. Morrison asserts that the black figure in the American literary tradition is pregnant with meaning when she writes that "the subject of the dream is the dreamer. The fabrication of an Africanist persona is reflexive; an extraordinary meditation on the self; a powerful exploration of the fears and desires that reside in the writerly conscious. It is an astonishing revelation of longing, of terror, of perplexity, of shame, of magnanimity." The black metaphor, she argues, is capable of conflicting and even contradictory meanings simultaneously. Through examining the uses of the black figure, the reader is able to discern the perspectives of the "dreamer" —that is, the writer—on the black other and on herself.

The revelation of longing, terror, perplexity, shame, and magnanimity Morrison cites in the "Africanist persona" did not spring up ex nihilo. My study argues that the profound anxiety about black characters found in English literature has its roots in the Middle Ages. Morrison states that race "has become metaphorical [in the modern era]—a way of referring to and disguising forces, events, classes, and expressions of social decay and economic division far more threatening to the body politic than biological 'race' ever was," but I argue that race was already metaphorical well before the biological "race" of the nineteenth century. Clearly, a black sultan who converts to Christianity and becomes white bears the requisite "perplexity." In a late medieval Christendom still reeling from the fall of the last Crusader stronghold in the Levant at Acre in 1291 and in which politicians and others still fantasized about Crusade, the sultan recalls Christendom's fears of eastern dominance while his conversion registers Christian longing for Muslim conversion. What is less clear and what I hope to show is that through the black sultan of the *King of Tars*, the medieval reader, like Morrison's "dreamer," is led to reflect upon his or her own spiritual state. ■

Cord Whitaker, Friends of the Institute for Advanced Study Member (2019–20) in the School of Historical Studies, is an Associate Professor at Wellesley College. This article is excerpted from Black Metaphors: How Modern Racism Emerged from Medieval Race-Thinking *with permission of the University of Pennsylvania Press (www.upenn.edu/pennpress). At IAS, Whitaker is working on his next book,* The Harlem Middle Ages: Color, Time, and Harlem Renaissance Medievalism.

Q&A with Member Cord Whitaker

On the value of the Middle Ages to the work of racial justice

What drew you to this field initially?

During my undergraduate career at Yale, I fell in love with medieval literature and Middle English language. It was only much later, during my graduate career, that I noticed something unexpected in the medieval romances I was studying for their implications regarding gender and medieval popular understandings of theology. These romances, it appeared, were quite interested in the development of identity—religious, geographical, and physiognomic. The dynamics I found reminded me quite a bit of what I knew to be the dynamics regularly employed in race and race-making in modernity.

Why IAS?

The Institute for Advanced Study offers me the opportunity to research in the company of fellow medievalists and other pre- and early modernists in the School of Historical Studies as well as colleagues in the School of Social Science who can speak to the seminal role of sociology in the development of critical race studies. The variety of expertise represented by IAS's community of scholars is integral to my current project, which examines medievalism not only in the literature of the Harlem Renaissance but also in the period's sociological work such as that of W.E.B. Du Bois and the philosophical writings of scholars such as Alain Locke.

Where is your favorite place to think?

My favorite place to think is near bodies of water, especially at the seashore. The calming swell and crash of the waves frees my mind to identify and explore connections—between texts, rhetorical devices, historical events, concepts, and ideologies—that have not yet been adequately explored.

What do you hope the impact of your research will be, now or in the future?

My research offers scholars, activists, and community organizers a new way to see race—as a rhetorical practice with historical roots that extend back well beyond the periods of Enlightenment science and American slavery to which it is often attached. My book *Black Metaphors* helps its readers understand the rhetorical and logical processes that went into creating race and racism.

Take, for example, the rhetorical device enthymeme, in which a proponent strengthens her position by inducing readers to presume a hidden premise and then presenting that premise's logical conclusion as a natural fact that relies on no premise at all. Enthymeme is a major element in racial ideology. When scholars, activists, and organizers are well versed in the deep rhetorical, logical, and ultimately psychological processes that undergird racism, they can develop effective strategies for studying them, disrupting them, for breaking the line of reasoning that takes as a hidden premise that blackness is a sign of spiritual depravity. No longer does the conclusion that black people are inclined to criminality, or otherwise inferior, appear natural.

My research, especially *The Harlem Middle Ages*, also aims to show readers the value of the Middle Ages to the work of racial justice. When Harlem Renaissance authors and intellectuals deployed the supposedly white Middle Ages in order to stake African Americans' claim to the entirety of the English literary and historical canons, they modeled the use of the Middle Ages and medievalism to shape politics and culture.

How do you describe your work to friends and family?

I tell friends and family that my work, especially my current project, unearths and examines the role of the Middle Ages in modern race; that, without the Middle Ages, the world as we know it, especially for black Americans, would not exist; and that Harlem Renaissance intellectuals, such as W.E.B. Du Bois, Jessie Redmon Fauset, and Alain Locke, among others, used the idea of medieval Europe—so wildly popular in the nineteenth-century America and Britain of their youth—to stake a black claim to the entirety of the American and English literary and cultural canons.

What other activities or subject areas do you enjoy?

In addition to enjoying medieval and African American literatures, I am an avid connoisseur of black musical forms—jazz, gospel, R&B, and hip-hop. I sing African American gospel music, and I have performed chorally and as a soloist with a number of groups over the past several decades. I also enjoy political analysis, and I am the founding co-editor-in-chief of *The Spoke*, the blog of the Madeleine K. Albright Institute for Global Affairs. ■

Curiosities: Partial Differential Equations

From the flow of air to the collapsing of a star to the spreading of a pollutant

BY CAMILLO DE LELLIS

A variety of systems in natural sciences are described through physically measurable quantities that depend on "independent variables." For instance, we routinely measure the pressure and the temperature of the air in the Earth's atmosphere, and such measurements depend upon the time and the location of the device used. Several fundamental laws discovered by scientists through the last three centuries give relations among the rates of change of such physical quantities. The resulting mathematical objects, called partial differential equations, are therefore ubiquitous in modern science and engineering: they are efficiently used to model a variety of different phenomena, like the flow of air past the wings of an airplane, the collapsing of a star into a black hole, or the spreading of a pollutant in the air.

The theoretical study of partial differential equations is a branch of pure mathematics that dates back to the dawn of modern sciences, originating in the works of Bernoulli, Fermat, Newton, Lagrange, Euler, and several others. Central theoretical questions are the existence of solutions, how they behave, what we need to know to determine them, and whether they break down, for instance, when they get in a range where the validity of the equations can be challenged. The latter phenomenon is usually called singularity formation. Such questions, especially the formation of singularities and their descriptions, are the main subjects of my research. The two topics in which I have spent most of my recent efforts are the calculus of variations and the equations of incompressible fluid dynamics.

In the calculus of variations, one seeks the solution of a minimum problem, for instance a shape that optimizes a certain feature. A prominent example is named after the Belgian nineteenth-century physicist Joseph Plateau, who proposed to study area-minimizing surfaces, namely surfaces which minimize their area among those which span a fixed contour. It is long known that such surfaces might have singularities, for instance, the formation of certain type of corners, but a complete description of the type and size of singularities is a long-standing open problem. I have shown with my collaborators that surprisingly many singularities can occur at the junction between an area-minimizing surface and its contour, even when the latter is quite simple and smooth. However, our work also gives the first proven theoretical limitation to the size of the singularities without any special geometric assumption on the contour. When the contour is a real analytic curve, a conjecture by White asserts that in fact there can be only finitely many singularities. A recent preprint authored by IAS Member Zihui Zhao and me gives a first step in that direction.


THOMAS ROBERT CLARKE

Camillo De Lellis

The first system of partial differential equations ever written down in fluid dynamics is given by the Euler equations, found by Leonhard Euler more than 250 years ago. The incompressible Euler equations are in fact a limiting case of another well-known system, the Navier-Stokes equations.

Whether regular solutions of the Euler and Navier-Stokes equations might form singularities in finite time is one of the biggest open problems in mathematics: for the Navier-Stokes equations, it is one of the famous millennium prize problems. In the last decade, I have shown with László Székelyhidi, Jr., that there are very irregular solutions, many more than expected, and that they might behave in a very surprising way. Our new approach borrows from the pioneering work of John Nash of the 1950s on the isometric embedding problem, a thus far completely unrelated topic in differential geometry, another branch of mathematics. My ideas with László are at the base of recent important developments, such as the resolution by Phil Isett of a 1949 fundamental conjecture of Lars Onsager (Nobel Prize winner in chemistry) in the theory of turbulent flows, and the unexpected discovery by Tristan Buckmaster and Vlad Vicol that irregular solutions of the Navier-Stokes system are not uniquely determined by the equations. ■

Camillo De Lellis is IBM von Neumann Professor in the School of Mathematics. A geometric analyst with broad expertise in the calculus of variations, geometric measure theory, and fluid dynamics, De Lellis joined the Institute's School of Mathematics as a Professor in 2018. Using modern tools and innovative approaches, De Lellis has contributed to central problems in analysis and geometry, resulting in the creation of a transparent proof of regularity and opening new lines of inquiry for geometric analysts to explore.

Q&A with Chris Maddison

On unsupervised learning, moments of surprise, and pursuing curiosity

In 2019–20, Chris J. Maddison, a Senior Research Scientist at DeepMind joins the School of Mathematics as a Member in the special year on Theoretical Machine Learning. While at IAS, Maddison is developing methods for machine learning and exploring foundational questions about how learning from data is possible.

What drew you to this field initially?
Relatively few species learn the vocalizations that they produce. Among them are humans, dolphins, and songbirds. At the outset of my undergraduate studies, I was interested in this question of how songbirds learn to sing. Towards the end of my studies, my interests had drifted into more foundational questions of how learning from data is possible in the first place. I became enamored with the algorithms of modern machine learning, and I've stuck with this field ever since.


ANDREA KANE

Chris Maddison

Why IAS?
The success of deep learning is owed to academic groups that pursued their research directions driven by curiosity and independently of the whims of academic trends. I was looking for a place to pursue curiosity wherever it led, connect with like-minded researchers, and focus on research. IAS seemed like a great place to do that; the spirit of curiosity is at the core of the Institute's culture and embodied in the title of Abraham Flexner's classic essay, "The Usefulness of Useless Knowledge."

What question within your field do you most want to answer and why?
An exciting question in machine learning is how to use apparently unlabeled data to improve performance on multiple downstream tasks. This is sometimes called unsupervised learning. It's a practical problem, because most data comes unlabeled by humans, but it is also a problem that is not paradigmatically settled. There are different proposed frameworks for unsupervised learning, but so far nothing emerges as a clear winner. There are even disagreements on how to measure progress!

Where is your favorite place to think?
When I am stuck in my research, a walk down a quiet woodland path is the best thing I can do to become unstuck.

What do you hope the impact of your research will be, now or in the future?
Some of the best moments in the study of computer science are when we collectively realize something is possible that was once considered improbable. We've been very lucky in machine learning to have many such moments; among them are the unrelenting progress of image classification algorithms, AlphaGo's win against Lee Sedol, and recent language models that can produce paragraphs of realistic artificial narratives. One of my goals is to contribute to these moments of surprise, to elicit the thought, "huh, that's cool."

How do you describe your work to friends and family?
Imagine you knew nothing about baking, but someone gave you a million different muffins. Could you figure out how to bake a muffin? That's the problem of machine learning.

What other activities or subject areas do you enjoy?
I enjoy reading poetry. I find it similar to the experience of reading a surprising proof or argument. When these are carefully written you can share in the moment of insight with the writer, and suddenly find yourself in a strange new world. I also enjoy making pottery on the wheel. ■

Could Physics and Mathematics One Day Unify?

Might a giant structure describe all the laws of the universe?

ANDREA KANE

Robbert Dijkgraaf (left), IAS Director and Leon Levy Professor, and Edward Witten (right), Charles Simonyi Professor in the School of Natural Sciences

The Institute for Advanced Study held a celebration of *The Universe Speaks in Numbers* by frequent Director's Visitor Graham Farmelo on May 29, 2019, which explored the astonishingly productive relationship between physics and mathematics. The public event, which was held on the centennial of the 1919 eclipse that provided the first experimental verification of Einstein's general theory of relativity, brought together some of the world's foremost science communicators for an afternoon of talks.

The program included an introductory talk by Farmelo; an interview with Freeman Dyson, Professor Emeritus in the School of Natural Sciences, and Karen Uhlenbeck, Distinguished Visiting Professor in the School of Mathematics by science writer and Director's Visitor (2017) Natalie Wolchover; a talk by Gregory Moore, Distinguished Visiting Professor in the School of Natural Sciences and Professor at Rutgers University, on the shapes of spaces and the nuclear force; a talk by Kyle Cranmer, Junior Visiting Professor in the School of Natural Sciences, on the primacy of experiment; a conversation between Nima Arkani-Hamed, Professor in the School of Natural Sciences, and collaborator Thomas Lam, von Neumann Fellow in the School of Mathematics; and a discussion between Robbert Dijkgraaf, IAS Director and Leon Levy Professor, and Edward Witten, Charles Simonyi Professor in the School of Natural Sciences, on the connections between math and physics, including some of the outstanding questions in quantum gravity, quantum field theory, and number theory.

Videos of the event—whose theme was whether physics and mathematics might one day unify, perhaps leading to a giant structure that encompasses all the laws that describe the underlying workings of the universe—may be viewed at www.ias.edu/ideas/videos-universe-speaks-numbers. Farmelo has also interviewed a number of IAS scholars past and present on the themes he explores in the book *The Universe Speaks in Numbers*, written while at IAS; to listen, visit www.ias.edu/news/farmelo-universe-speaks-interviews. ■

Edward Witten on Mathematics and Physics

By the twentieth century, mathematics had advanced into rather abstract realms, transcending its origins, which had been largely driven by questions closer to the natural world. Physics on the other hand, especially after the development of quantum mechanics, went in directions that were much harder for mathematicians to appreciate. Two of our speakers this afternoon, both Karen [Uhlenbeck] and Tom [Lam], drew attention to the fact that it is actually extremely difficult for mathematicians to understand quantum field theory. And that's been an enduring mystery.

Since quantum field theory has been increasingly central in physics since the late 1920s, that has created, just in the logic of mathematics and physics, a gulf between them. And that was enhanced after World War II. In the quarter-century after World War II, there was an incredible flood of discoveries in fundamental physics, so that the progress of physics was largely driven by experiment in a way that might not have made the subject seem too enticing to mathematicians, especially given that the mathematical foundations were so murky. That would be kind of a summary of where the world was when I was a student, for example.

When I was a student, a physics graduate student would not be exposed—I was not, and I think others would not have been either—to any ideas at all in contemporary mathematics or really even in twentieth-century mathematics, practically. Now, clearly, things have changed a lot since then. And one of the biggest reasons that things have changed is that when the Standard Model of particle physics developed, theory, in a way, had caught up with experiments. When the Standard Model was in place, it led physicists to ask new kinds of questions that weren't possible before, without the Standard Model. And it made what physicists could potentially do more interesting mathematically.

So, definitely, this story has changed in the period since I was a graduate student. And string theory has also been an important part of that change. I would like to remark though that although there has been a huge change since I was a student, we shouldn't exaggerate. There is also still a big separation, an almost inescapable separation, between the goals and nature of the two subjects.

Physicists usually are not much interested in the details of mathematical proofs, which means that usually even physicists might not really understand deeply the mathematical ideas that they are working with. And, on the other hand, since the difficulty for mathematicians to understand quantum field theory has endured, it remains extremely difficult for mathematicians to understand what physicists are really trying to do.—*Edward Witten, Charles Simonyi Professor in the School of Natural Sciences, in conversation with Robbert Dijkgraaf, IAS Director and Leon Levy Professor*

Of Historical Note: When arXiv Was Born

In 1989, Joanne Cohn, a physicist then at the Institute for Advanced Study, began distributing TeX files of string theory papers via email. By August of 1991, the email list had grown to 180 physicists—an unwieldy number for Cohn to individually respond to requests for papers. As Cohn recounts, a young physicist then at Los Alamos National Laboratory offered to automate the list, and arXiv was born. "Day one, something happened, day two, something happened. Day three, Ed Witten posted a paper," said Cornell University physicist Paul Ginsparg, founder of arXiv.org. "That was when the entire community joined."—*from "Preprints Make Inroads Outside of Physics,"* APS News*, American Physical Society, October 2019, www.aps.org/publications/apsnews/201909/preprints.cfm*

LURIE *(Continued from page 1)*

Atiyah, Vladimir Voevodsky, and André Weil—a tradition that will surely be further enhanced by Jacob's work at the Institute."

Lurie's celebrated proof of the Baez-Dolan cobordism hypothesis changed the field drastically, providing a precise dictionary between manifold theory and operadic algebra as well as an applicable language for topological field theory. Embracing an extraordinary breadth of vision, his ideas have touched a diverse range of fields from topology to number theory.

"Lurie's foundational work changed the way that mathematicians describe and work with derived phenomena," said Akshay Venkatesh, Robert and Luisa Fernholz Professor in the School of Mathematics. "It has had a remarkably broad influence on modern mathematics."

Lurie has written two major books, *Higher Topos Theory* (2009) and *Higher Algebra* (2011), and is currently at work on a third, *Spectral Algebraic Geometry.* These volumes, along with a sequence of papers concerned with derived algebraic geometry, have redefined the foundations of homotopy theory and topological aspects of algebraic geometry, providing a powerful environment for groundbreaking research in emerging and classical fields. Lurie's work provides a channel through which algebraic topology influences algebraic geometry. In this respect, his work follows in the tradition of the late IAS Professor Vladimir Voevodsky.

"I'm truly honored to be afforded this opportunity and thrilled to become a part of the long tradition of mathematics at the IAS," remarked Lurie.

Lurie earned a B.A. in Mathematics from Harvard University (2000), pursued graduate studies at Princeton University and the University of California, Berkeley, and received a Ph.D. in Mathematics from the Massachusetts Institute of Technology in 2004.

Lurie was awarded the 2016 London Mathematical Society Hardy Fellowship in recognition of his outstanding contributions to the field, in particular through his seminal work on derived algebraic geometry, higher category theory, stable homotopy theory, and topological field theory. He was a recipient of the inaugural 2015 Breakthrough Prize in Mathematics, and was named a 2014 MacArthur Fellow for creating a novel conceptual foundation for derived algebraic geometry and rewriting large swathes of mathematics from a new point of view. ■

Singular Adventures of Baron Bourgain in the Labyrinth of the Continuum

A tribute to one of the most original, penetrating, and versatile analytical minds

BY ALEXANDER GAMBURD

> There are two labyrinths of the human mind: one concerns the composition of the continuum, and the other the nature of freedom, and both spring from the same source—the infinite. —*Baron von Leibniz*

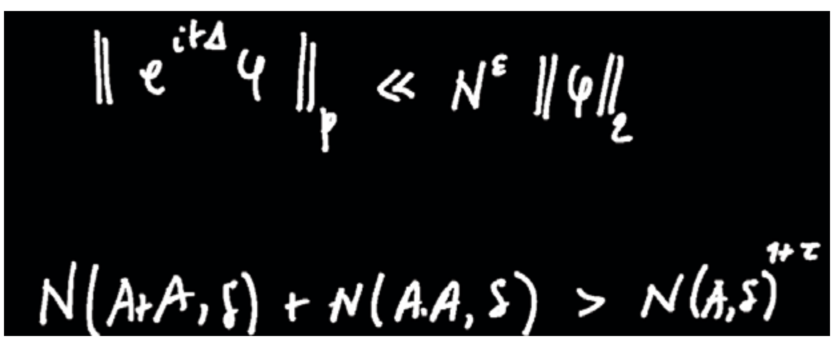
> During World War II, when von Neumann was working on the design of nuclear weapons, he came to the conclusion that analytical methods were inadequate to the task, and that the only way to deal with equations of continuum mechanics is to discretize them.… It is to this task that von Neumann devoted his energies after the war. —*Peter Lax*

Overture

Baron Bourgain, the IBM von Neumann Professor in the School of Mathematics at the Institute for Advanced Study, is one of the most original, penetrating, and versatile analytical minds of our troubled times, justly celebrated and revered without reservations.

While he rejected outright the suggestion of a sixtieth birthday conference, a proposal to have a gathering occasioned by the publication of his 500th paper was not immediately dismissed—the conference "Analysis and Beyond: Celebrating Jean Bourgain's Work and its Impact" took place at the IAS in Princeton on May 21–24, 2016. The conference talks (available at www.ias.edu/analysis-and-beyond) are a tribute to the depth and breadth of Bourgain's work and its singular and transcendent impact on the whole of our discipline. The beauty and power of the first result highlighted by Jean's hand on the conference poster is apparent from reading the splendid paper by Andrea Nahmod in the *Bulletin of the American Mathematical Society*, 2016. The brief of this paper is to explicate the origins, nature, and development of the second result, *the discretized sum-product inequality*, in analysis and beyond.

> The three great branches of mathematics are, in historical order, Geometry, Algebra, and Analysis. Geometry we owe essentially to Greek civilization, algebra is of Indo-Arab origin, and analysis (or calculus) was the creation of Newton and Leibniz, ushering in the modern era. —*Sir Michael Atiyah*



Two important equations in Jean Bourgain's hand, the second of which, known as Bourgain's discretized sum-product inequality, is the subject of this paper

Von Zahlen und Figuren — *On Numbers and Shapes* is the title of one of the most successful expositions of mathematics aimed at a broad audience, reflecting a common perception of our discipline as a marriage between algebra and geometry. This happy marriage, notwithstanding Count Tolstoy's contention ("All happy marriages are alike; each unhappy marriage is unhappy in its own way."), is not without tensions (as, perhaps, each happy marriage—including, possibly, bicameral mind—is in its own way). "In these days the angel of topology and the devil of abstract algebra fight for the soul of each individual mathematical domain" is the way Hermann Weyl put it in 1939.

This tension is embodied in the system of real numbers, the soil in which the functions of analysis grow, resembling Janus's head facing in two directions: on the one hand, it is the field closed under the operations of addition and multiplication; on the other hand, it is a continuous manifold the parts of which are so connected as to defy exact isolation from each other. The one is algebraic, the other is the geometric face of real numbers. Continued fractions is a much more intrinsic and geometric form of discretizing the continuum; the lack of a practical algorithm for their addition and multiplication leads to the regnancy of the discretization based on the ordinary (digital or decimal, i.e., base 10) fractions.

Whereas Newton, in his development of calculus, was primarily motivated by "dynamics" (force, acceleration), as exemplified by the falling of the apple on his head, Leibniz, it appears, was more intrigued by what would now be described by the appellation *fractal geometry of nature*. "Imagine a circle; inscribe within it three other circles congruent to each other and of maximum radius; proceed similarly within each of these circles and within each interval between them, and imagine that the process continues ad infinitum," wrote Leibniz referencing

From Left to Right: Alex Gamburd, Peter Sarnak, and Jean Bourgain

configuration akin to the four mutually tangent circles appearing on Baron Bourgain's coat of arms. Leibniz's definition of the straight line as a "curve, any part of which is similar to the whole, and it alone has this property, not only among curves but among sets" is a reflection of the fractal nature of the continuum: the Cantor set would satisfy Leibniz's definition.[1]

Dynamics, broadly conceived, is perceived as a study of change, which in its primordial (physical) context takes place within time. The Cantor set (and the continuum) are timeless, i.e., static in time, but there is "a condition of possibility" of (almost) "equi-primordial" change "in the eye of the beholder," taking form in changing the degree of magnification scale and "zooming in." This is reflected in the "multi-scale" nature of Bourgain's proof(s) of the discretized sum-product inequality.

To bring this opening section to a close, let us in passing note that both results chosen by Jean are not equalities (inequalities, rather), commenting thus:

If algebra is generally perceived as the study of equations, what perhaps lies at the heart of analysis are inequalities, or estimates, which compare the size of two quantities or expressions. Einstein's discovery that nothing travels faster than light is an example of an inequality. The inequality 2^X *is considerably larger than* X arguably neatly encapsulates both the P vs NP problem (properly stated for finite X) and Cantor's continuum problem (when X is the first unfinite ordinal). An elementary inequality, taught in the middle school, asserts that the arithmetic mean of two positive numbers is never less than their geometric mean. In between these extremes, there is a vast range of estimates of great variety and importance. Such estimates, reflecting and quantifying some subtle aspect of the underlying problem, are often exceedingly difficult to prove. It will be seen that for the discretized sum-product inequality, with which we are about to get intimate, the underlying issue lies at the heart of the tension between the algebraic and (fractal)–geometric nature of the continuum. Fractal derives from Latin *fractus*, meaning broken apart; algebra, derives from the Arabic *al-jabr*, meaning the reunion of broken parts.

Origins: Kakeya-Besicovitch Problem

Hilbert's democratic dictum, "Mathematical problem is not perfect unless you can explain it to the first man whom you meet on the street," if followed by Sōichi Kakeya (writing the paper on an island nation in 1917, at the height of the Great War), the explanation of the problem now bearing his name to almost every person on just about any street in Eastern Eurasia, might have run as follows: Entrusted with defending an island, possessing a huge hill, cragged and steep, your task is to purchase at the least cost to the nation's treasury, a plot of land on the flat hilltop with the following property: a cannon of length one must be capable of pointing in any direction.

Kakeya improved by a factor of one-half the obvious solution (a circle of diameter one, having area $\pi/4$). His proposed shape was a three-cusped hypocycloid inscribed in the circle of radius 1. In the same year, working in Perm (subsequently Molotov, 1940–57; currently Perm), while the October/November Russian/Soviet Revolution was unfolding, A. S. Besicovitch reduced the minimal necessary sum to virtually nothing.

While the Kakeya set in the plane (two-dimensional space) has measure zero, it has fractal dimension 2 (see footnote 2). The basic conjecture is that in higher-dimensional spaces the same phenomenon holds: e.g., a set containing a line pointing in every direction in the three-dimensional space has fractal dimension 3.

 (Continued from page 18)

This conjecture, central to many problems in harmonic analysis, has been the subject of intense study by some of the most outstanding analysts of our time, with the major breakthrough by Bourgain in 1999, in which he related the Kakeya problem to arithmetic combinatorics.

Sum-product phenomena and the labyrinth of the continuum

One of the basic results in arithmetic combinatorics is the "sum-product phenomenon," whose elementary and elemental nature might be described as follows. When studying addition and multiplication tables for numbers from 1 to 9, one might notice that there are many more numbers in the multiplication table. This basically has to do with the fact that the numbers from one to nine form an arithmetic progression. If you take a set forming an arithmetic progression (or a subset of it) and add it to itself, it will not grow much; if you take a set forming a geometric progression (or a subset of it) and multiply it by itself, it will also not grow much. However, a subset of integers cannot be both an arithmetic and a geometric progression, and so it will grow either when multiplied or added with itself. This is expressed as a statement $|A + A| + |A{\cdot}A| \geq |A|^{1+\tau}$ valid for any *finite* set of real numbers; here $|A|$ measures the size of the set, i.e., the number of elements in it.

Bourgain's discretized sum-product inequality $N(A + A, \delta) + N(A \cdot A, \delta) > N(A, \delta)^{1+\tau}$ deals with *infinite* subsets of the continuum and measures their size in terms of "metric entropy" $N(A, \delta)$, which is the least number of balls of diameter δ needed to cover A. To oversimplify, the inequality says that for an arbitrary subset of the continuum, subject to mild technical assumptions, the fractal dimension would grow when it is multiplied or added to itself.

Discrete and Continuous Variations on the Expanding Theme

Expanders are highly connected sparse graphs widely used in computer science. Clearly high connectivity is desirable in any communication network. The necessity of sparsity is perhaps best seen in the case of the network of neurons in the brain: since the axons have finite thickness, their total length cannot exceed the quotient of the average volume of one's head and the area of the axon's cross-section. In fact, this is the context in which expander graphs first implicitly appeared in the work of Barzdin and Kolmogorov in 1967.

Now, there are basically two sources of raw material for constructing mathematical structures: randomness and number theory. It was observed early on that random regular graphs are expanders. The explicit construction of optimal expanders—Ramanujan graphs—used deep number–theoretic results from the theory of automorphic forms to construct expanders as Cayley graphs of groups[3] with respect to some very special choices of generators.

A basic question that arose in 1994—at the time when I was starting my Ph.D.—is to what extent the expansion is the property of groups alone, independent of the choice of generators. I became fascinated/obsessed with this problem and obtained some partial results in my thesis under the direction of Peter Sarnak in 1999. In the fall of 2005, in joint work with Jean, we were able to finally resolve the problem in many cases by bringing in some recently developed tools from additive combinatorics, related to the sum-product phenomena.

These developments are discussed by Jean in his lecture "Expansion in Linear Groups and Applications" (available at www.ias.edu/bourgain-linear-groups); see also: www.ias.edu/gamburd-math-marvels.

Coda

In attempting to explain the significance of Bourgain's remarkable and remarkably useful results to a proverbial human-on-line, one may invoke their applications in mathematical physics, computer science, and cryptography, which are of immense practical importance in contemporary life, making, in particular, the on-line communication possible. Their subtlety, beauty, and depth appear to be much harder to convey in "plain English." Here and now, perhaps, we must remind ourselves that the human-on-line, while attached to a digital device (built by von Neumann) is still human and sound-bite/tweet thus: while dealing with entities seemingly fake/unreal (e.g., the real line), Bourgain's singular adventures in the labyrinth of the continuum represent a magnificent and transcendent achievement of the human spirit.

I met Jean in September 2005, six months after my daughter was born, while visiting IAS for the program "Lie Groups, Representations and Discrete Mathematics," led by Alex Lubotzky.[4] I do not remember the precise date but do remember the hour: it was between 2 and 3 a.m. After changing my daughter's diapers, I could not sleep, went to Simonyi Hall, and ran into Jean walking to the library. It was in this discombobulated state that I was free of fear to speak to him. By dawn, the problem which had been resisting my protracted attack for a decade was vanquished in Jean's office.[5]

During this happiest year of my life, in 2005–06, I stayed on the lane named after Hermann Weyl who was of the view that "Mathematics is not the rigid and uninspiring schematism which the laymen is so apt to see in it; on the contrary, we stand in mathematics precisely at that point of limitation and freedom which is the essence of man himself."

The seal of the IAS (where Jean did most of the work described in this essay) is a quiet, elegant, and classical Art Deco composition depicting two graceful young ladies, one clothed (Beauty) and one otherwise (Truth), standing on opposite sides of a leafy tree that appears to bear abundant fruit. Underlaying the design of the seal is the evident allusion to the famous final couplet of "Ode on a Grecian Urn" by John Keats, who was of the view that "the excellence of every art is its intensity, capable of making all disagreeables evaporate from their being in close relationship with Beauty and Truth."

Having attempted in this essay a snapshot of the excellence of Bourgain's art, let me conclude by giving a glimpse of his intensity by quoting from the interview upon his receiving the 2017 Breakthrough Prize in Mathematical Sciences:

> If you have a question which is generally perceived as unapproachable, it is often that you do not even quite know where you have to look to get a solution. From that point of view, we are rather like Fourier stranded in the desert, hopelessly lost. At the moment you get this insight, all of a sudden you escape the desert and things open up for you. Then we feel very excited. These are the best moments. They make up for all the suffering with absolutely no progress worth it. ■

Recommended Viewing: From May 31–June 1, 2019, IAS hosted a remembrance in honor of Jean Bourgain. The public event brought together colleagues, friends, and collaborators—including Professors Peter Sarnak and Avi Wigderson, several past Members, and others—to commemorate Bourgain's life and work. Watch talks from the event at www.ias.edu/ideas/bourgain-remembrance-videos.

To Jean Bourgain
from the people from Banach spaces
1994

Who makes a paper every week,
and every month a new technique,
and founds new branches every year,
and does not know the sense of fear?
And legends—whom d'you hear about?
And if you met him you'd be proud.
Of course, he made his early traces
in the romantic Banach spaces,
and he obtained his glory there,
and after that went everywhere.
And everybody is excited
and says he's almost always cited,
you read a paper and again:
you see the name of Jean Bourgain!

Alexander Gamburd, a Member (2007–08, 2005–06) in the School of Mathematics, is Presidential Professor of Mathematics at the Graduate Center, City University of New York. Published here are slightly edited excerpts from his essay "Singular Adventures of Baron Bourgain in the Labyrinth of the Continuum," to be published by the American Mathematical Society (online draft available at www.ias.edu/gamburd-singular-adventures).

1. Leibniz also wrote the first textbook on combinatorics *Dissertatio de arte combinatoria* and invented the binary notation, which made possible modern computers and will play an important role in navigating the labyrinth of Bourgain's argument. The first collection of Leibniz's works was published in 1735 by Rudolf Erich Raspe, better known today for his authorship of *Singular Adventures of Baron Munchausen*.
2. If A is a curve, it is easy to see that $N(A, \delta)$ is of order δ^{-1}. If A is a surface, $N(A, \delta)$ is approximately δ^{-2}. This suggests the idea of defining the fractal dimension of an arbitrary set as the number d for which $N(A, \delta) \sim \delta^{-d}$.
3. The Cayley graph of $PSL_2(\mathbf{F}_p)$ for $p = 5$ with respect to standard generators is a buckyball.
4. https://mathinstitutes.org/highlights/expander-graphs
5. Jean had the following daily routine. He would arrive at the dining hall for lunch within 5 minutes of its closing and, while descending the stairs, would look for whom to join for the meal (the relevance of the person was determined primarily by their expertise in the problem Jean was currently working on). After lunch and before sunset, the door of his office would be half-open. After getting a bottle or red wine (typically Medoc), Jean would have dinner around 9 p.m., followed by a double espresso (typically at Small World Coffee), return to the office, call his wife and son, and then go for a brisk walk, encircling the Einstein Drive five times or so. Between midnight and sunrise, the office door would typically be closed. His handwritten notes (like that of Mozart's and unlike Beethoven's) are virtually free of corrections, in part, because during the dinner and the walk he would think about what would be set to paper upon his return to the office.