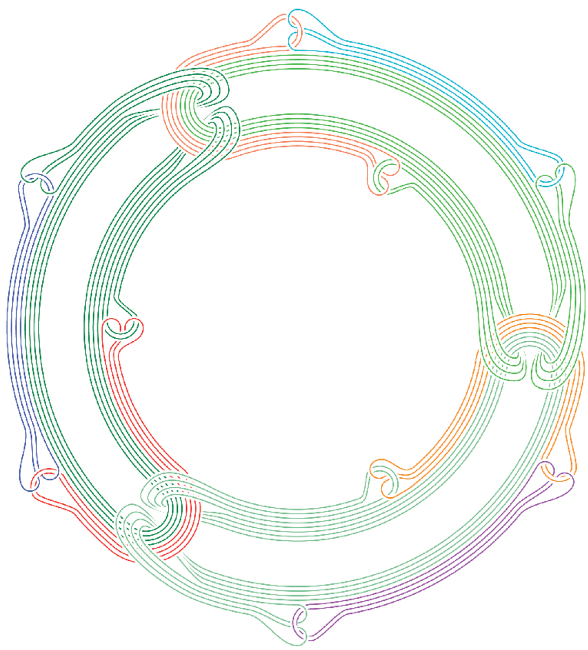
IAS

The Institute Letter

Spring 2013



NILS A. BAAS AND ANDREW STACEY, NTNU, NORWAY

This tangle of rings is an example of a higher order structure studied by Nils Baas, a joint Member in the Schools of Mathematics and Natural Sciences.

At the Institute, scholars and scientists are interested in the underlying structures across the sciences and humanities that influence the way the world has moved and continues to move around us. In this issue, Faculty and Members consider the underlying structures of migration, genetic data, the building blocks of quantum mechanics and mathematics, and rhetorical speech. These structures are enormously powerful, but they can be difficult to discern. By studying only partially perceivable forces and hypothesizing about aspects not yet understood, researchers are trying to unlock valuable insights that can lead to revolutions in our understanding of nature and society. Often, they are looking to apply what they have learned about structures in one setting to another seemingly unrelated setting.

Professor **Patrick Geary** writes about his efforts to use genetic data, and what we know about its underlying structure, to understand how evolving societal structures and population movements transformed the Roman world at the end of antiquity (page 1). Member **Deva Woodly** looks at how the underlying structure of speech can prompt successful social movements (page 1). Member **Nils Baas** writes about trying to find hidden structures in biological information (page 10). Professors **Enrico Bombieri**, **Freeman Dyson**, **Peter Sarnak**, and **Thomas Spencer** explain efforts to understand a mysterious structure, discovered at the Institute more than forty years ago, that connects prime numbers—the building blocks of mathematics—and random matrices—the building blocks of quantum mechanics (page 1). And Professors **Nima Arkani-Hamed** and **Juan Maldacena** describe the rigid yet fragile structure that led to the recent discovery of the Higgs particle and what new questions it might lead us to answer (page 6).

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Institute for Advanced Study

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Using Genetic Data To Revolutionalize Understanding of Migration History

Presumed Longobard settlements, first to sixth centuries

BY PATRICK J. GEARY

Few historical questions have so fascinated historians as the fall of the Roman Empire or, in the more fashionable modern parlance, its "transformation" into something altogether different, namely independent kingdoms ruled by successors of barbarian commanders in the West and a Greek-speaking Byzantine Empire in the East. For over two centuries, historians have particularly debated the role of barbarian invasions in this process, but in reality we have very little hard data on the nature of the barbarian "peoples" that entered the Western provinces between the fourth and sixth centuries, their numbers, their composition, or the reality of their influence on the indigenous populations of the Empire.

Were these large ethnic populations moving across Europe from Scandinavia to Italy and Spain, as nineteenth-century romantics imagined? Or were they small heterogeneous military units employed by the Empire that settled, with a minimum of force and disruption, within the administrative and fiscal mechanisms of a still-functioning Empire, as has been suggested more recently? Did these groups long maintain their distinctiveness from the local population, eschewing intermarriage and holding fast to their distinctive legal and

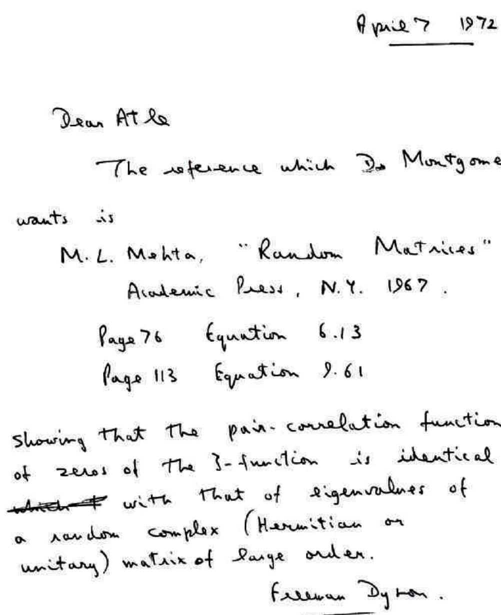
(Continued on page 5)

From Prime Numbers to Nuclear Physics and Beyond

In early April 1972, Hugh Montgomery, who had been a Member in the School of Mathematics the previous year, stopped by the Institute to share a new result with Atle Selberg, a Professor in the School. The discussion between Montgomery and Selberg involved Montgomery's work on the zeros of the Riemann zeta function, which is connected to the pattern of the prime numbers in number theory. Generations of mathematicians at the Institute and elsewhere have tried to prove the Riemann Hypothesis, which conjectures that the nontrivial zeros (those that are not easy to find) of the Riemann zeta function lie on the critical line with real part equal to ½.

Montgomery had found that the statistical distribution of the zeros on the critical line of the Riemann zeta function has a certain property, now called Montgomery's pair correlation

(Continued on page 8)



April 7 1972

Dear Atle

The reference which Dr Montgomery wants is

M. L. Mehta, "Random Matrices" Academic Press, N.Y. 1967.

Page 76 Equation 6.13

Page 113 Equation 9.61

Showing that the pair-correlation function of zeros of the ζ-function is identical ~~which~~ with that of eigenvalues of a random complex (Hermitian or unitary) matrix of large order.

Freeman Dyson.

After his teatime conversation with Hugh Montgomery, Freeman Dyson wrote this letter to Atle Selberg with references showing that the pair-correlation of the zeros of the zeta function is identical to that of the eigenvalues of a random matrix.

Reviving Rhetoric: An Aristotelian Interpretation of the Campaigns of Political Underdogs

BY DEVA WOODLY

I was in my final year of graduate school, writing a dissertation on the place of persuasion in the success of contemporary American social movements, when the nearly two-year-long campaign for the American president who would succeed George W. Bush began. As a student of politics, it was impossible not to be transfixed by the epic discursive battle being waged, first in the hard-fought democratic primary between Hillary Clinton and Barack Obama and finally during the general election campaign in which, Obama, having won against his formidable Democratic rival, entered a political contest with veteran politician John McCain. For the American public, this contest was the most closely followed election in decades. A Gallup poll taken in June 2008, early summer, when political attention is usually at its nadir, found that nearly two-thirds of Americans described the 2008 campaign as "exciting." By September, Gallup found that a record 87 percent, almost nine in ten Americans, reported that they were following national politics closely. The astonished poll takers wrote, in the summary of their results,

An Obama supporter holds up a "Yes We Can" sign as President-elect Barack Obama gives his victory speech during a 2008 election night gathering in Grant Park.

"This significantly exceeds anything Gallup has measured since it began asking this question in 1995."*

The excitement generated by the election was due to a number of factors, among them: the contest was for an open seat, no incumbent was on the ballot, and the field of candidates was unusually strong. The Democratic primary, in particular, had included a number of rarities, including the first woman frontrunner for party nomination and only the third African American candidate to ever enter the Democratic party's nominating contest. These two candidates, each of whom would be "firsts" in the American presidency, emerged as the strongest in the field, and their struggle for primacy was dramatized by a long and highly competitive primary process. In one corner was the well-known and much admired senator from New York and former first lady, Hillary Clinton, and, in the other, the newly minted senator from Illinois, a rhetorical and organizing powerhouse with the "funny name," Barack Obama. Americans, usually bored by and cynical about political contests, were transfixed.

As a researcher studying how political underdogs,

(Continued on page 16)

News of the Institute Community

PATRICK J. GEARY, Professor in the School of Historical Studies, has been elected as a Corresponding Fellow of the Akademie der Wissenschaften zu Göttingen.

History of the Present: A Journal of Critical History, edited by JOAN WALLACH SCOTT, Harold F. Linder Professor in the School of Social Science, as well as former Members in the School, ANDREW AISENBERG (1991–92), BRIAN CONNOLLY (2005–06), BEN KAFKA (2009–10), and SYLVIA SCHAFER (2000–01), has been named Best New Journal for 2012 by the Council of Editors of Learned Journals. *History of the Present* provides a forum for the critical examination of history, considering both its influence on politics and the politics of the discipline of history itself.

The Guide to PAMIR: Theory and Use of Parameterized Adaptive Multidimensional Integration Routines by STEPHEN L. ADLER, Professor Emeritus in the School of Natural Sciences, has been published by World Scientific Publishing Company (2012). The book gives a user's manual, and related theory, for the multidimensional integration programs written by Adler that can be downloaded at www.pamir-integrate.com. The programs can follow localized peaks and valleys of the integrand, and come in parallel versions for cluster use as well as serial versions.

Oxford University Press has published *The Throne of Adulis: Red Sea Wars on the Eve of Islam* by GLEN W. BOWERSOCK, Professor Emeritus in the School of Historical Studies. The book reconstructs an overlooked chapter in pre-Islamic Arabian history—an international war between Christian Ethiopians and Jewish Arabs in southern Arabia just prior to the rise of Islam in the sixth century—and draws on descriptions of an inscribed marble throne at the Ethiopian port of Adulis as well as a wealth of other historical and archaeological evidence.

ARNOLD J. LEVINE, Professor Emeritus in the School of Natural Sciences, has been named as a Fellow in the inaugural class of the American Association for Cancer Research Academy.

Contents

Questions and comments regarding the *Institute Letter* should be directed to Kelly Devine Thomas, Senior Publications Officer, 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/about/publications.

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

ROBBERT DIJKGRAAF, Director of the Institute and Leon Levy Professor, formally announced the coronation of the new King of the Netherlands, Willem-Alexander, on April 30; he was selected as one of five Heralds, each representing a field of expertise. Dijkgraaf, who will receive an honorary doctorate from Radboud University Nijmegen in the Netherlands on May 24 and was named an Honorary Fellow of the Royal Society of Edinburgh, was also elected a member of the American Academy of Arts and Sciences.

DAVID M. RUBENSTEIN, a Trustee of the Institute, has been elected a member of the American Academy of Arts and Sciences and has received the David Rockefeller Award from the Museum of Modern Art in honor of his advocacy of cultural and civic endeavors. Rubenstein is Co-Founder and Co-Chief Executive Officer of the Carlyle Group.

VARTAN GREGORIAN, a Trustee of the Institute, has received the Distinguished Service Award from the Council on Foundations. The award honors an individual who embodies the intellect, integrity, leadership, and accomplishments that define excellence in the field of philanthropy. Gregorian is President of the Carnegie Corporation.

The 2013 New Horizons in Physics Prize of the Fundamental Physics Prize Foundation has been awarded to ZOHAR KOMARGODSKI, long-term Member in the School of Natural Sciences, and DAVIDE GAIOTTO, former long-term Member (2007–12) in the School. Komargodski was cited for his work on the dynamics of four-dimensional field theories, which has solved a long-standing problem and led to important insights. Gaiotto, who is currently a member of the faculty of the Perimeter Institute for Theoretical Physics, was recognized for far-reaching work on duality, gauge theory, and geometry, and for linking theories in different dimensions in unexpected ways.

Two former Members in the School of Mathematics, MICHAEL ARTIN (1983) and GEORGE DANIEL MOSTOW (1947–49, 1956–57, 1975–76, 1990), have won the 2013 Wolf Prize in Mathematics. Artin was recognized for his fundamental contributions to a number of areas of algebraic geometry. Mostow was recognized for pioneering work on geometry and Lie group theory, including work done jointly with Pierre Deligne, Professor Emeritus in the School.

MANJUL BHARGAVA, former Member (2001–02) in the School of Mathematics, has won the 2012 Infosys Prize for Mathematical Sciences for his original work in algebraic number theory. Bhargava is Professor at Princeton University.

The Mathematical Association of America awarded its Chauvenet Prize to ROBERT GHRIST, former Visitor (1995) in the School of Mathematics, for his article "Barcodes: The Persistent Topology of Data" in the *Bulletin of the American Mathematical Society* 45 (2008). Ghrist is Andrea Mitchell Penn Integrates Knowledge Professor at the University of Pennsylvania.

The Leroy P. Steele Prize for Mathematical Exposition was awarded to former Members JOHN M. GUCKENHEIMER (1970–72, 1988–89) and PHILIP HOLMES (2003) for their book *Nonlinear Oscillations, Dynamical Systems, and Bifurcations of Vector Fields* (Springer, 1983). Guckenheimer is Abram R. Bullis Professor of Mathematics at Cornell University, and Holmes is Eugene Higgins Professor of Mechanical and Aerospace Engineering and Professor of Applied and Computational Mathematics at Princeton University.

DAVID JERISON, former Member (1991–92) in the School of Mathematics, has been awarded the 2012 Stefan Bergman Prize from the American Mathematical Society. Jerison was honored along with John M. Lee for their work on the CR Yamabe problem. Jerison is Professor and MacVicar Faculty Fellow at the Massachusetts Institute of Technology.

YOSEF KAPLAN, former Member (2007–08) in the School of Historical Studies, has been selected to receive the 2013 Israel Prize for his research on the history of the Jewish people. Kaplan is Bernard Cherrick Professor Emeritus of the History of the Jewish People at the Hebrew University of Jerusalem.

The American Mathematical Society E. H. Moore Research Article Prize was awarded to MICHAEL J. LARSEN, former Member (1988–90) in the School of Mathematics, along with Richard Pink, for their article "Finite Subgroups of Algebraic Groups" (*Journal of the American Mathematical Society* 24, 2011). Larsen is Distinguished Professor at Indiana University.

AVI LOEB, former Member (1988–93, 2002–03) in the School of Natural Sciences, has received the 2013 Chambliss Astronomical Writing Award from the American Astronomical Society for his book *How Did the First Stars and Galaxies Form?* (Princeton University Press, 2010). Loeb is Frank B. Baird, Jr. Professor of Science at Harvard University and Director of the Institute for Theory and Computation at the Harvard-Smithsonian Center for Astrophysics, Harvard University.

The American Mathematical Society–Society for Industrial and Applied Mathematics Norbert Wiener Prize in Applied Mathematics was awarded to ANDREW J. MAJDA, former Member (1988, 1991–92) in the School of Mathematics, for his work on theoretical fluid mechanics and its applications in atmospheric science and oceanography. Majda is Samuel F. B. Morse Professor of Arts and Science at the Courant Institute of Mathematical Sciences, New York University.

FERNANDO CODÁ MARQUES, former Member (2008) in the School of Mathematics, has received two prizes in recognition of his contributions to differential geometry. The Ramanujan Prize of the International Centre for Theoretical Physics was awarded to Marques by the Neils Henrik Abel Memorial Fund and the International Mathematical Union. The TWAS Prize was awarded by the Academy of Sciences for the Developing World (TWAS), recognizing, in particular, his work on variational problems in conformal geometry and applications of the theory of Ricci flow. Marques is Professor at the Instituto Nacional de Matemática Pura e Aplicada in Rio de Janeiro.

WILLIAM NEWMAN, former Member (2000–01) in the School of Historical Studies, has been selected to receive the 2013 HIST Award of the American Chemical Society Division of the History of Chemistry. Newman is Distinguished Professor and Ruth Halls Professor of History and Philosophy of Science at Indiana University.

The American Mathematical Society David P. Robbins Prize was awarded to ALEXANDER RAZBOROV, former Member (1993–94) and Visiting Professor (2000–08) in the School of Mathematics, for his article "On the Minimal Density of Triangles in Graphs" (*Combinatorics, Probability and Computing* 17, 2008). Razborov is Andrew MacLeish Distinguished Service Professor at the University of Chicago.

The American Mathematical Society Leroy P. Steele Prize for Lifetime Achievement was awarded to YAKOV G. SINAI, former Member (1991) in the School of Mathematics. Sinai was recognized for his pivotal role in shaping the theory of dynamical systems, as well as his groundbreaking contributions to ergodic theory, probability theory, statistical mechanics, and mathematical physics. He is Professor at Princeton University.

Pierre Deligne Awarded 2013 Abel Prize

The Norwegian Academy of Science and Letters has awarded the 2013 Abel Prize to Pierre Deligne, Professor Emeritus in the School of Mathematics. Deligne was cited by the Abel Committee for his "seminal contributions to algebraic geometry and for their transformative impact on number theory, representation theory, and related fields." Deligne's novel ideas and resolution of long-standing problems have permeated these fields to the point where a significant portion of current research cannot be formulated without reference to his work.

"Deligne's focus extends beyond establishing fundamental mathematical truths; he seeks to understand why they are inevitable," noted Peter Sarnak, Professor in the School of Mathematics. "In his work, this is often achieved by brilliant abstract reasoning, after which the result becomes clear and conceptual. Deligne is responsible for many of the standard tools in modern algebraic geometry, and a range of striking theorems, theories, mathematical objects, and constructions bear his name."

Robbert Dijkgraaf, Director of the Institute and Leon Levy Professor, added, "We are extremely pleased that Pierre's work is being acknowledged by the Abel Prize. His keen insight and total dedication as a mathematician are matched only by his great mentorship and generous spirit, which have inspired generations of researchers here at the Institute and around the world."


CLIFF MOORE

Pierre Deligne

The Abel Prize acknowledges outstanding scientific work in the field of mathematics and comes with a monetary award of approximately one million U.S. dollars. The Prize will be given to Deligne by H. M. King Harald at an award ceremony in Oslo on May 21, and Deligne will deliver a lecture the following day. Since the Abel Prize was first bestowed in 2003, ten of the eleven recipients have been affiliated with the Institute as Faculty or Members.

Among Deligne's contributions are his proof of the Riemann Hypothesis for varieties over finite fields (also known as the Weil Conjectures, named for André Weil, Professor at the Institute from 1958 until 1998), the proof of the Ramanujan Conjecture in the theory of modular forms, and a proof of a vast generalization of Hilbert's twenty-first problem concerning linear differential equations and monodromy groups. He introduced the idea of "weights" in Hodge theory, a powerful proof technique and a useful conceptual tool. Deligne has made significant contributions to representation theory, number theory, and automorphic forms. *Quantum Fields and Strings: A Course for Mathematicians* (1999), edited by Deligne and others, presented material from the collaborative mathematics and physics seminars held at the Institute in 1996–97 and has become the standard source for mathematicians on this topic.

Deligne was born in 1944 in Etterbeek, Brussels, in Belgium, and he pursued mathematics from a young age. At age twelve, he was intrigued by his older brother's textbooks, and further affirmed his passion for mathematics after reading Nicolas Bourbaki's *Elements of Mathematics*, recommended by his high school teacher. Deligne received his Licence en Mathématiques (B.A.) in 1966 and his Ph.D. in 1968, both from the University of Brussels. In 1967–68, Deligne was concurrently a junior scientist at the Belgian National Fund for Scientific Research and a guest at the Institut des Hautes Études Scientifiques (IHÉS). He was a visiting member at IHÉS from 1968–70, at which time he was appointed a permanent member. In 1972, Deligne earned his Doctorat d'État ès Sciences Mathématiques from Université Paris-Sud 11. He was a Member (1972–73, 1977) and Visitor (1981) in the School of Mathematics at the Institute. He was appointed to the Faculty of the Institute in 1984 and became Emeritus in 2008.

Deligne has received many distinguished international awards in recognition of his work and impact across the field, including the Fields Medal (1978), the Crafoord Prize (1988, jointly with Alexander Grothendieck), the Balzan Prize (2004), and the Wolf Prize (2008, jointly with Phillip Griffiths and David Mumford). He is also the recipient of the François Deruyts Prize (1974), the Henri Poincaré Medal (1974), and the A. De Leeuw-Damry-Bourlart Prize (1975). In 2006, Deligne was honored by King Albert II of Belgium, who made him a Viscount. The Belgian post office also issued a postage stamp in honor of his achievements in fundamental mathematics. Deligne is a member of many of the world's leading scientific academies and societies. He is an honorary member of the Moscow Mathematical Society and of the London Mathematical Society, a foreign honorary member of the American Academy of Arts and Sciences, a member of the American Philosophical Society, and a foreign member of the Royal Swedish Academy of Sciences. ■

Sebastian Currier Appointed as Artist-In-Residence

The Institute has announced the appointment of composer Sebastian Currier as Artist-in-Residence beginning July 1, 2013. Currier, recipient of the 2007 Grawemeyer Award, one of the world's most prestigious awards for musical composition, will curate the Institute's Edward T. Cone Concert Series as well as pursue his creative and intellectual work as part of the Institute's community of scholars.

The *Washington Post* has called Currier's music, which has been performed by artists and orchestras worldwide, "lyrical, colorful, firmly rooted in tradition, but absolutely new." In 2007–08, his chamber music was presented by the Berlin Philharmonic, including three world premieres. The violinist Anne-Sophie Mutter has performed Currier's *Aftersong* extensively in the United States and Europe, including in New York's Carnegie Hall and London's Barbican. Mutter premiered Currier's violin concerto *Time Machines* with the New York Philharmonic in 2011, a piece called "rapturously beautiful" by Anthony Tommasini in the *New York Times*.


JEFFREY HERMAN

Sebastian Currier

"We are immensely pleased that Sebastian Currier will be coming to the Institute as Artist-in-Residence," said Robbert Dijkgraaf, Director and Leon Levy Professor at the Institute. "We see this appointment as a reflection of the growing role of the music program and the wonderful contributions of previous Artists-in-Residence. The Institute and the community of music lovers in the Princeton area will be greatly enriched by his distinctive voice."

Currier has created several works that involve electronic media and video. In *Next Atlantis*, premiered by the American Composers Orchestra at Carnegie Hall in 2010, a string orchestra converses with recorded sounds of water, evoking the lost city. In *Nightmaze*, a multimedia piece based on a text by Thomas Bolt, a protagonist dreams he is rushing along a dark highway, where strange road signs loom and disappear. "Currier's rich and imaginative music sets the right tone," wrote the *Times*, "with its fractured and dissonant baroque-like gestures leading off like highway exits into the void and hinting at distant reservoirs of emotion and yearning." New works premiering during the 2012–13 season include *Deep-Sky Objects*, for soprano and ensemble; *Fifteen Minutes*, for flute, harp, and viola; and *Quanta*, for orchestra.

BRUCE M. WHITE

"I look forward very much to participating in the intellectual and creative life of the Institute, which is an extraordinary, unprecedented organization," said Currier. "I am thrilled to have the opportunity to interact with such an exciting and distinguished community."

The Artist-in-Residence program was established in 1994 to create a musical presence within the Institute community and to have in residence a person whose work could be experienced and appreciated by scholars from all disciplines. Artists-in-Residence organize the Edward T. Cone Concerts at the Institute, an annual series of free concerts that are open to the public. The series is named for the late Edward T. Cone, a distinguished composer, musical scholar, and Princeton University Professor who had longstanding ties to the Institute.

Pianist Robert Taub was the first Artist-in-Residence from 1994 to 2001, followed by composer Jon Magnussen, who served as Artist-in-Residence from 2000 to 2007, and Paul Moravec, who served as Artist-in-Residence from 2007 to 2008 and Artistic Consultant from 2008 to 2009. Currier succeeds composer and clarinetist Derek Bermel, who was named Artist-in-Residence in 2009.

"Sebastian's creative integrity, brilliance, and boundless curiosity are a fine match for the Institute," said Bermel. "During my tenure here, I've been both inspired by working alongside first-rate scientists and scholars, and touched by the seriousness with which this community engages with music. I'm excited to see what this new chapter in the Artist-in-Residence program brings."

Currier has received numerous honors in addition to the Grawemeyer Award, including the Berlin Prize, the Rome Prize, a Guggenheim Fellowship, and an Academy Award from the American Academy of Arts and Letters. He has held residencies at the MacDowell and Yaddo colonies, and, from 1999–2007, he taught at Columbia University. He holds a Doctor of Musical Arts degree from the Juilliard School.

Currier's *Quartetset/Quiet Time* album (New World Records, 2006), recorded by the Cassatt Quartet, makes listeners "think about music itself," Anne Midgette wrote in the *New York Times*, while also being "eminently listenable." Other recordings of his work include *Time Machines*, with Anne-Sophie Mutter and the New York Philharmonic on Deutsche Grammophon (2011); *Next Atlantis*, with the Ying Quartet on Naxos (2010); and *On the Verge* from Music from Copland House, featuring *Static* and other chamber works. Currier's music is published by Boosey & Hawkes. ■

Ancient History: The Director's Cut

Oliver Stone at the Institute for Advanced Study

BY ANGELOS CHANIOTIS

The study of cinematic representations of ancient history is one of the most rapidly rising fields of classical scholarship. As an important part of the modern reception of classical antiquity, movies inspired by Greek and Roman myth and history are discussed in academic courses, conferences, textbooks, handbooks, and doctoral theses. Such discussions involve more than a quest for mistakes—a sometimes quite entertaining enterprise. They confront classicists and ancient historians with profound questions concerning their profession: What part does the remote past play in our lives? How do modern treatments of the past reflect contemporary questions and anxieties? How is memory of the past continually constructed, deconstructed, and reconstructed?

My father worked in the movie industry in the 1950s and 60s as a producer and leaseholder of one of Greece's largest movie theaters. This may have been the impetus for me to become a cinephile. However, my fascination with the representation of history on the big screen is part of my interest in how memory is shaped. Many Members of the School of Historical Studies, past and present, share this interest. Adele Reinhartz (Member, 2011–12) is the author of *Scripture on the Silver Screen* (Westminster John Knox Press, 2003) and *Jesus of Hollywood* (Oxford University Press, 2007); among current Members, the archaeologist Yannis Hamilakis studies the place of the past in modern Mediterranean societies and their media; the ancient historian Nathanael Andrade incorporates movies into undergraduate teaching; and the historian of Latin America Jeff Gould directs historical documentaries.

A discussion at the Institute about history on screen was, therefore, overdue, and the ideal person to kick off such a discussion was Oliver Stone. No other contemporary director has treated controversial historical subjects so often and with so much passion, especially important episodes of postwar American history. His treatment of history reached its high point this year with the release of the documentary *The Untold History of the United States*, directed, produced, and narrated by Stone and coauthored with Peter Kuznick. An accompanying book was published in 2012. For these reasons, I invited Oliver Stone to deliver this year's S. T. Lee Lecture. His remarks were followed by a panel discussion and questions from the audience.

Stone visited the Institute, accompanied by his son Sean Stone, a director and actor. He spoke with Faculty and Members, and, in the company of Freeman Dyson, was shown the Institute's archive. His conversations with Freeman Dyson touched upon J. Robert Oppenheimer, the Institute's third Director (1947–66), and the predictability of scientific developments in the future.

Clockwise from left: (1) Freeman Dyson talks with Oliver Stone during their visit to the Institute archives; (2) Oliver Stone discusses making his film Alexander*; (3) from left: Nathanael Andrade, Angelos Chaniotis, Oliver Stone, Gary Leva, and Yannis Hamilakis discuss historiography in the context of cinema.*

In his talk in Wolfensohn Hall, Stone focused on his film *Alexander*, a fourth version of which is in preparation. He shared with the audience his passion for the man who arguably and most radically changed the course of ancient history through his campaigns from his native Macedonia to India. Following a tradition that goes back to Johann Gustav Droysen's *History of Alexander the Great* (1833)—the book that laid the foundation for the study of Alexander—Stone narrated the story of a man driven by passion and vision, inspired by mythical heroes, haunted by childhood memories, bereft of his greatest love, and surrounded by suspicion and betrayal. Listening to Stone speak, one could easily be seduced to believe that his is the narrative of an eyewitness, not a modern interpretation of ancient sources. This is where a cinematographic approach to history has a clear advantage over that of the scholarly historical narrative: it creates in the audience the illusion of "being there" and, in so doing, makes strong impressions, arouses empathy, provokes thoughts.

Angelos Chaniotis, Professor of Ancient History and Classics in the School of Historical Studies, is internationally regarded for his original and wide-ranging research in the social, cultural, religious, legal, and economic history of the Hellenistic world and the Roman East. He works in innovative ways on a wide variety of topics: war, memory, identity, emotions, the communicative aspects of rituals, and strategies of persuasion in the ancient world.

After Stone's lecture, the director Gary Leva, Adjunct Professor of Film at the University of Southern California's School of Cinematic Arts, talked about the documentarian's approach to making a movie about Alexander. By showing a short segment of his film, in which several scholars and a professional soldier respond very differently to the question of whether Alexander was a "multiculturalist," Leva demonstrated the challenges a director faces when dealing with such a controversial subject. Two other panelists introduced the audience to two further aspects of "history on screen." Member Nathanael Andrade of the University of Oregon explained various possibilities of integrating movies with historical subjects into undergraduate teaching. Member Yannis Hamilakis of the University of Southampton discussed the role of material culture in movies inspired by ancient themes and the political exploitation of cinematic representations of antiquity.

Recommended Viewing: A video of "(Ancient) History on Screen," a lecture at IAS by Oliver Stone, supported by the Dr. Lee Seng Tee Fund for Historical Studies, may be viewed at http://video.ias.edu/stone-event-1-13.

The audience's conversation with Stone brought a variety of subjects to the fore: the reasons for the fascination with Alexander, the relationship between film and documentary, the difficulties in finding an audience for movies inspired by history, the selection of actors, the relationship between historical "facts" and dramatization, and the reliability of the source material. "I read everything I could. . . . But you couldn't make the character, you couldn't make this movie from those sources," said Stone. "I had to plunge in and create the Alexander. I had to break down the third and fourth walls. There is just no way you could put it together from those memories. But the love of the men was there; you felt it, and you can hear about it."

Stone also addressed one of the main objectives of the *The Untold History of the United States*: to discuss the role of the United States in the contemporary world and to problematize the concept of a world empire. "We look at the history of the last hundred years, we look at the victims of this U.S. policy, and we try to make one understand that it did not need to be so," said Stone. "We always argue that it needed to be so because we were fighting communism and we were fighting terrorism. We argue not. We go through an enormous amount of work to prove that. And I think we make the point about looking at the world through global eyes, through Chinese eyes, through Russian eyes, through small countries' third-world eyes. We try to see that we are part of something that is bigger than just the American empire." Stone concluded with an encouragement for young people to change the world. "Young people can change the world. Young people can dream. That's the beauty of Alexander, because he is one of the last young people to achieve significant power and do something about it. Can we do something like this in our country? Can someone change the course of where we are heading?"

In the second century B.C.E., the historian Polybios criticized his fellow historian Phylarchos for writing in such a manner that his readers had the impression that they were eyewitnesses to what he was narrating. Eager to arouse pity and empathy among his readers, Phylarchos talked of women clinging to one another, tearing their hair and baring their breasts, and of lamentations of women, children, and aged parents led away in captivity. Polybios resented all that, because he made a sharp distinction between the treatment of the past by the tragic poet, who seeks to thrill and charm an audience in the moment, and the historian, who seeks to educate for all time. Polybios may be right in distinguishing between history and drama, but he is wrong in all other respects: in his assumption that empathy can be separated from cognition, and emotion from reason, and in his assumption that drama is less instructive than historiography. Twenty-two centuries later, audiences have the illusion that they are eyewitnesses of events not thanks to the words of skillful narrators, but thanks to the moving images presented to them by the directors of feature movies and documentaries. The motion picture, the most popular form of dramatization, entertains, educates, and fills us with empathy. In this respect, it is an ally of the historian, not a rival. The dialogue of historians with Oliver Stone indicated the possibilities of interplay between scholarly history and the screen. Welcoming Stone, the Institute's Director Robbert Dijkgraaf called the occasion of a film director's visit to the Institute "a first." The success of this event justifies a sequel: to be continued . . . ■

cultural traditions, or did they rapidly integrate themselves into local elites through intermarriage and cultural transformation? Were they really distinct population groups at all or merely provincial Romans and local "barbarians" who united under ethnic labels and took advantage of opportunities to seize power from a beleaguered empire? Traditional sources with which to answer these questions—highly rhetorical accounts of the period often written centuries later, sparse administrative documents surviving in scattered fragments, and ambiguous archaeological material showing changing patterns of burial custom and settlements—simply do not provide enough evidence to reach a consensus.

More recently, a new kind of source, genetic data, has begun to be employed in an attempt to gain a new perspective on migration-era Europe, part of the widespread popularity of DNA research and a tendency to look to "science" to cut through the fuzzy speculations of historians and humanists. In an age obsessed with identity politics that looks increasingly to genetics to answer the fundamental question "Who am I?", distributions of genetic markers across populations are being seen as proxies for ethnic and racial differences. In the words of Keith Wailoo, a historian of science and public affairs at Princeton University, the result is "lending renewed authority to biological conceptions of human difference and providing fodder for national debates over belonging, self-definition, and political power."[1] It is also producing bad history.

To cite but one example, a recent study announced the discovery of a "western Eurasian" in a two-thousand-year-old elite Xiongnu cemetery in northeast Mongolia and suggested that the presence of an "Indo-European" was possibly evidence of "the racial tolerance of the Xiongnu."[2] Can genetic analysis actually demonstrate that an individual was from a specific region of the Eurasian landmass, in this case from western Eurasia? Can it actually be evidence that he spoke an Indo-European language? Can it be evidence that the Xiongnu were racially tolerant? Such claims are wildly exaggerated and such conclusions deeply problematic. What they actually found was an individual with the maternal U2e1 and paternal R1a1 haplogroups. R1a is the most common haplogroup in Europe, suggesting that it was statistically more likely but not at all certain that at some point his paternal ancestors had a western origin, and less likely that they were indigenous to the region in which he died. The fact that his genetic makeup bore some similarities with some modern Indian populations is absolutely no basis on which to term him an "Indo-European"—this is a linguistic, not a geographical, and certainly not a genetic term, and genotype is not equivalent to "race." Such shifts from a biological to an essentializing cultural identity, common in the nineteenth and the first half of the twentieth centuries, have no place in modern scholarship. Other studies, based on DNA sampling of contemporary European populations, have attempted to argue for a massive replacement of male chromosomal material in eastern England between the fifth and eighth centuries, suggesting either the slaughter and expulsion of virtually all of the male British population of eastern Britain or else a form of "Anglo-Saxon apartheid" practiced by Anglo-Saxon invaders at the end of the Roman Empire.

ANDREA KANE

Patrick Geary (far left) organized an informal seminar with Faculty and Members from the Simons Center for Systems Biology and the School of Historical Studies in February.

Is this the best that genetics can offer migration history? I don't think so, and I would like to suggest some possible areas in which genetic history might actually contribute to research projects exploring migration history. If, instead of using genetic evidence to look for essences, one uses this evidence to uncover one aspect of social construction, of transcultural and trans-societal flows, of movement and of transformation, then genetic history becomes both meaningful and exciting. The problem, of course, is how to do this.

Until recently, most attempts to use genetic evidence to write history suffered from two fundamental problems. First, until a decade or so ago, most historians attempted to work with contemporary DNA samples taken from living persons to trace their ancestors in order to understand earlier populations. While this may be effective for very early events (such as the dispersion of humans from Africa across Eurasia), it is very dubious evidence of more recent historical events such as medieval migrations, because it assumes extremely stable communities both before and after the events one hopes to study. Secondly, if scientists attempted to work with DNA taken from medieval graves, relatively little genetic data could be extracted from ancient tissue. This was essentially mtDNA, a non-recombinant portion of one's DNA inherited exclusively from one's mother. Moreover, this data is such a small portion of the entire human genome that to base conclusions from it alone is, to paraphrase a metaphor of the British geneticist Mark Thomas, like reading a single page of a five-hundred-page book and drawing some conclusion about its contents. The result has been to ignore the complexity of the wider genetic data to essentialize communities by hiding the complexity of human ancestry.

What we will not do is try to identify which among our samples are "real" Longobards or whether the Longobards are the "real" ancestors of the modern inhabitants of Lombardy. We want to get beyond ethnic and political labels and understand the movements of people and their cultural and demographic impacts on the population of Europe in the past.

Today, thanks to extraordinary advances in genetic sequencing, it is at last possible to analyze the entire human genome of long-dead individuals and to study ancient populations at an extraordinarily fine-grained level. Using this "next-generation sequencing" it is possible to look at past populations in their complex genetic heterogeneity, to recognize fairly distant kinship relationships, and to gauge genetic distances separating individuals and populations. In the most ambitious attempt to apply these new techniques to study medieval migrations to date, I have assembled a team of geneticists, archaeologists, physical anthropologists, and historians to study migration of people living in Pannonia (what is now eastern Austria, Hungary, and the Czech Republic) into Italy in the second half of the sixth century. Historically, this migration/invasion is credited to the Longobardi, or Lombards, who established a kingdom in Italy that endured until the late eighth century and whose name lives on in Lombardia in Italy. Without assuming the veracity of historical sources written centuries later that tell of King Alboin leading his Longobards across the Alps in 568, we are studying the DNA of hundreds of individuals from cemeteries in Pannonia and Italy. Using next-generation sequencing, we hope to target distinct parts of the genome: approximately five thousand distinct locations along the genome called single nucleotide polymorphisms, or SNPs, are known to be useful in differentiating individuals from different regions of Europe and will allow us to look at close kinship among our populations; and five thousand regions of one thousand base pairs of continuous DNA sequence (a total of five megabases or 0.2 percent of the whole genome) will allow us to test competing models of the demographic history of this region. The results of this sequencing, which will take place in laboratories in Florence and Milan, must then be analyzed, both by examining what is termed unsupervised analysis—that is, direct analysis of the SNPs using such tools as principal component analysis and ancestry component analysis in order to find actual relationships and patterns—and, just as importantly, by testing a wide range of models derived from population genetics, cultural archaeology, and historical records, that might allow us to test the relative probability that any of the models might best explain our data. Ultimately, we hope to be able to construct a model of the populations of Pannonia and Italy in the late sixth century that can help us understand whether individuals identified by cultural archaeologists as "Longobards" based on their grave goods have closer genetic relationships with each other than with individuals buried according to what appear to be very different cultural traditions. We want to know if there are close relationships between similar cultural groups in Pannonia and Italy, or if the apparent cultural differences mask genetic homogeneity. We hope to determine whether men and women seem to have different histories of migration: do men move and marry local women, or are men more fixed and bring women from distant areas into their homes?

What we will not do is try to identify which among our samples are "real" Longobards or whether the Longobards are the "real" ancestors of the modern inhabitants of Lombardy. We want to get beyond ethnic and political labels and understand the movements of people and their cultural and demographic impacts on the population of Europe in the past. The project is at its initial phase of collecting genetic samples and doing the preliminary sequencing. We still face formidable obstacles: ancient DNA is notoriously difficult to sequence; obtaining good samples requires complex international negotiations and unusual interdisciplinary cooperation; and the costs of next-generation sequencing and analysis are considerable. Nevertheless, I am energized by the opportunity to lead a pioneering project with the potential of revolutionizing our understanding of the population changes that transformed the Roman world at the end of antiquity. ■

1 Keith Wailoo, Alondra Nelson, Catherine Lee, eds., *Genetics and the Unsettled Past: The Collision of DNA, Race, and History* (Rutgers University Press, 2012), 2.

2 Kijeong Kim, et al., "A Western Eurasian Male is Found in 2000-Year-Old Elite Xiongnu Cemetery in Northeast Mongolia," *American Journal of Physical Anthropology* 142, no. 3 (2010): 429–40.

Patrick J. Geary, who first came to the Institute as a Member in the School of Historical Studies in 1990–91, joined the School as a Professor in January 2012. He is a leading historian of the Middle Ages whose research has opened new ways to understand, interpret, and define the medieval past. His work extends over a vast range of topics in medieval history, both chronologically and conceptually from religiosity to language, ethnicity, social structure, and political organization.

Discovering the Higgs: Inevitability, Rigidity, Fragility, Beauty

Following the discovery in July of a Higgs-like boson—an effort that took more than fifty years of experimental work and more than 10,000 scientists and engineers working on the Large Hadron Collider—Juan Maldacena and Nima Arkani-Hamed, two Professors in the School of Natural Sciences, gave separate public lectures on the symmetry and simplicity of the laws of physics, and why the discovery of the Higgs was inevitable.

Peter Higgs, who predicted the existence of the particle, gave one of his first seminars on the topic at the Institute in 1966, at the invitation of Freeman Dyson. "The discovery attests to the enormous importance of fundamental, deep ideas, the substantial length of time these ideas can take to come to fruition, and the enormous impact they have on the world," said Robbert Dijkgraaf, Director and Leon Levy Professor.

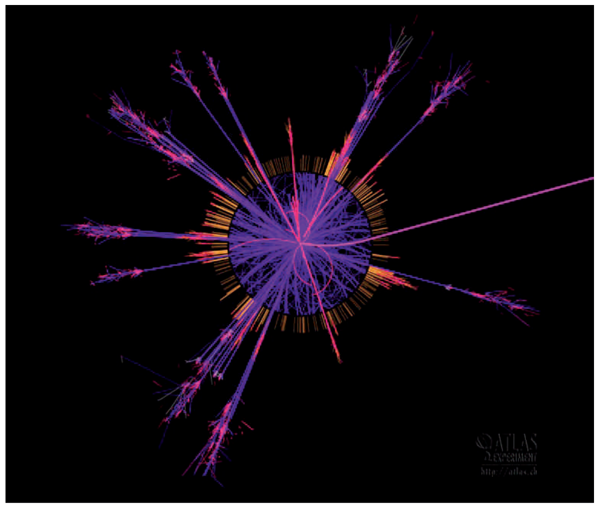
In their lectures "The Symmetry and Simplicity of the Laws of Nature and the Higgs Boson" and "The Inevitability of Physical Laws: Why the Higgs Has to Exist," Maldacena and Arkani-Hamed described the theoretical ideas that were developed in the 1960s and 70s, leading to our current understanding of the Standard Model of particle physics and the recent discovery of the Higgs-like boson. Arkani-Hamed framed the hunt for the Higgs as a detective story with an inevitable ending. Maldacena compared our understanding of nature to the fairytale *Beauty and the Beast*.

"What we know already is incredibly rigid. The laws are very rigid within the structure we have, and they are very fragile to monkeying with the structure," said Arkani-Hamed. "Often in physics and mathematics, people will talk about beauty. Things that are beautiful, ideas that are beautiful, theoretical structures that are beautiful, have this feeling of inevitability, and this flip side of rigidity and fragility about them."

The recent discovery of the Higgs-like boson is "a triumph for experiment but also a triumph for theory," said Arkani-Hamed. "We were led to saying, 'This thing has got to be there. We've never seen one before, but by these arguments, by our little detective story, it's gotta be there.' And by God, it is. It's allowed to be there. It can be there. It is there."

In Maldacena's comparison, beauty is the fundamental forces of nature—gravity, electromagnetism, the strong force, and the weak force—and the beast is the Higgs mechanism. "We really need both to understand nature," said Maldacena. "We are, in some sense, the children of this marriage."

Current knowledge of the fundamental forces of physics is based on two well established theories: the Standard Model of particle physics, a set of equations that gives an impressively accurate description of elementary particles and their interactions, but omits gravity and only accounts for about one-sixth of the matter in the universe; and Einstein's theory of general relativity, which describes the observed gravitational behavior of large objects in the universe, such as galaxies and clusters of galaxies, but has yet to be reconciled with quantum principles.



Gauge symmetries determine the interactions and production of particles (as depicted here). Juan Maldacena used a monetary analogy to describe the gauge symmetries of the electromagnetic and weak force.

Ordinary matter—the material we see and are familiar with, such as the planets, the stars, human bodies, and everyday objects—is acted on by gravity, electromagnetism, the strong force, and the weak force. These interactions apply over an enormous range of distances—from the size of the observable universe (around 10^{28} centimeters) down to the weak scale (around 10^{-17} centimeters).

In the Standard Model of particle physics, nature is built out of elementary building blocks, such as electrons and quarks. Forces between particles are transmitted by other particles, such as photons, the carrier of electromagnetic forces, and W and Z particles, the basic particles that transmit the weak interactions. The Higgs isn't the first particle that the Standard Model has predicted and that has been later discovered experimentally. The model also has led to the prediction and discovery of the W and Z particles, the top quark, and the tau neutrino.

The Higgs boson explains how most fundamental particles acquire mass as they interact with a Higgs field that exists everywhere in the universe. It is the final element of the Standard Model that needed to be confirmed experimentally and its discovery promises to provide further understanding of the origin of mass and help clarify some long-standing mysteries.

The weak scale is the distance that is being probed at the Large Hadron Collider, where the Higgs-like boson was discovered. With all ordinary matter and interactions, the force between two electrons (the size of the quantum mechanical fluctuations) gets weaker as you go to longer distances (lower energies) and stronger at shorter distances (higher energies), a basic consequence of the Heisenberg uncertainty principle.

"We've learned that the essential unity and simplicity of the laws of nature become manifest at short distances," explained Arkani-Hamed. "They're hidden at large distances by a variety of accidents, but when we go to short distances we finally see them. We see for the first time all these different interactions described in a common way."

In the Standard Model, all particles intrinsically have some spin and an angular momentum that is associated with that spin. Known particles have angular momenta, measured in H-bar (Planck's constant) units, in multiples of 1/2. According to the model, the only allowable spins are 0, 1/2, 1, 3/2, and 2, but we have seen only a subset of that: 1/2, 1, and 2. The electron has spin 1/2. The photon has spin 1. The graviton, which interacts the same with everything, is the only particle that has spin 2.

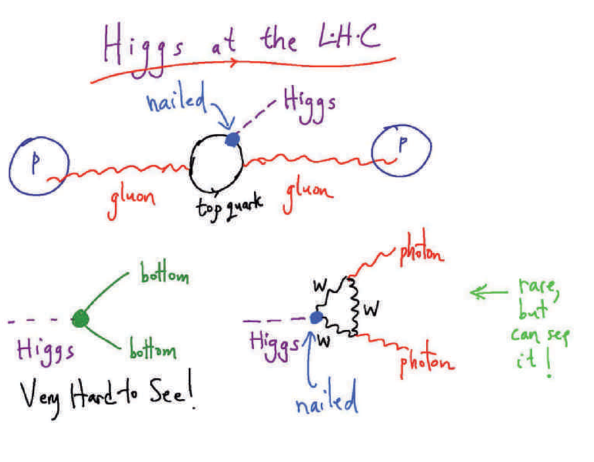
The story of the Higgs starts by trying to understand why some particles have mass. According to the Standard Model, the W and Z particles that carry the electroweak force should have zero mass to allow for the unification of the electromagnetic and weak nuclear forces in a single electroweak force. Between theory and experiment, it was determined that the Higgs particle had to enter the picture under 200 GeV (a unit to measure mass), that it had to interact with W, Z, and top quark particles, and that it had to have 0 spin. While the Standard Model did not predict the exact mass of a Higgs particle, from precise measurements, it was known that it had to be somewhere between 80 to around 200 times the mass of a proton. The Higgs-like boson, which was discovered last summer in the mass region of around 126 GeV, allows once-massless particles to have mass without destroying the principles of the Standard Model.

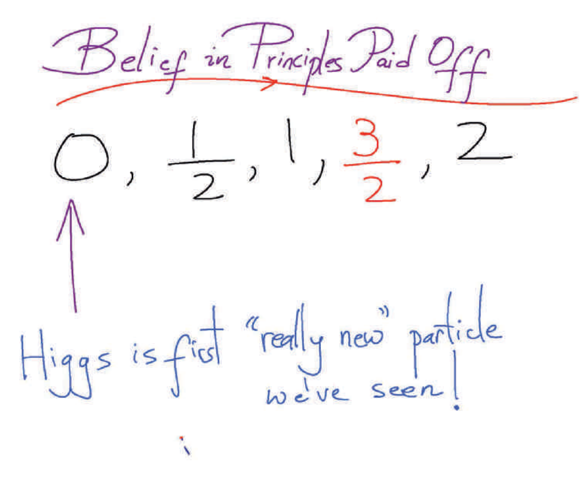
"People sometimes ask, what is this [the discovery of the Higgs] useful for?" said Maldacena. "I have to be honest, I don't know of any technological application. There is the apocryphal quote of [Michael] Faraday. When asked what the possible technological application of electricity was, he said to the prime minister, 'Someday we will be able to tax it.' I think, maybe, we could say the same thing about the Higgs boson. Something we do know is that it is helping us understand what happens in nature at very short distances."

Gauge symmetries determine the interactions and production of particles, and Maldacena used a monetary analogy to describe the gauge symmetries of the electromagnetic and weak force. In his analogy, the magnetic field is a gauge symmetry where each country is identical except they can choose their own currency. All money must be changed to the new currency when moving from country to country.

In physics, the currency is the rotations within a circle at each point in spacetime, and the exchange rate is the electromagnetic potential, or the displacement that results from traveling from one small spacetime region (country) to the next. Following a quantum mechanic understanding of the probabilistic laws of nature, "these exchange rates are random with a probabilistic distribution that depends on the opportunity to speculate," said Maldacena. "Nature doesn't like speculation, and will not offer you these opportunities very easily, but it will offer them to you, if you can find them."

The gauge symmetry of weak interactions involves symmetries of spheres rather than circles at each point in spacetime. Maldacena described the Higgs mechanism as an object sitting at each point on these weak spheres. When a rotation is made—even in a vacuum and empty space—this mechanism causes a transformation or change.





Slide images on this page and page 7 from Nima Arkani-Hamed's lecture, "The Inevitability of Physical Laws: Why the Higgs Has to Exist."

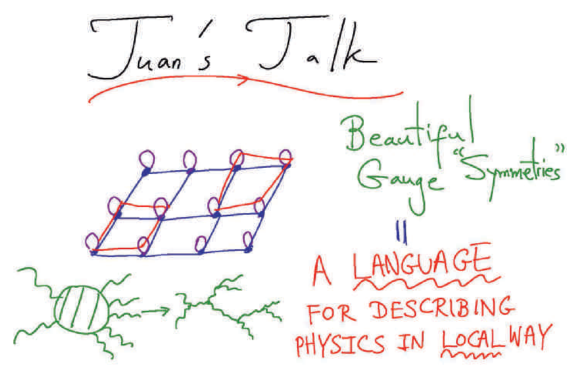
(Continued on page 7)

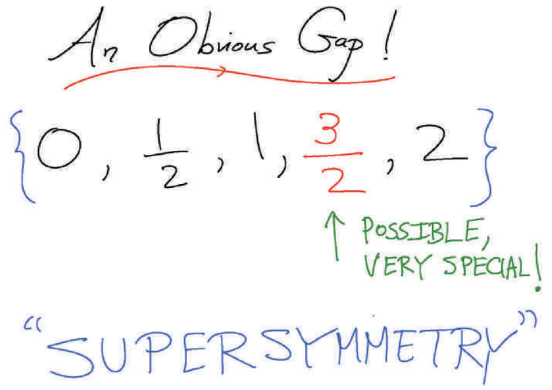
HIGGS LECTURES *(Continued from page 6)*

Continuing the monetary analogy, Maldacena introduced the notion of being able to buy something, in this case gold, in each country. The gold can be taken from one country to the next, its price is set by each of the countries, and money can be earned by going back and forth between the countries. In this analogy, the price of gold in each country is the Higgs field. Once the price or gauge is set to a constant value everywhere in space, this leads to a preferential value for the exchange rates, and leads to the masses for the W and Z weak bosons. In Maldacena's analogy, the Higgs boson arises when there are two objects, such as gold and silver, to purchase. The relative price of gold and silver is the Higgs boson; the ratio behaves as a massive particle. According to Maldacena, it is necessary to have at least two objects to buy so that when the distances between points in spacetime becomes very small we can still retain interesting interactions at long distances.

The Higgs-like boson was produced at the LHC in an indirect way but according to similar gauge symmetries derived from the Standard Model. When protons collide, they produce many particles. Very rarely, they produce Higgs bosons. These Higgs bosons decay very quickly into particles, such as two photons. Since the Higgs bosons decay too quickly to discern, theorists predicted that experimentalists could detect the Higgs by looking at events that have two photons and finding a bump in the data where two photons would amount to the mass of the Higgs boson.

The Higgs boson is the first particle with spin 0. This leaves only spin 3/2 unrealized in nature. But there is a strong candidate. Supersymmetry is associated with 3/2, and it is possible that the LHC will confirm the existence of supersymmetry, which extends the Standard Model and unites matter particles and force particles by pairing them in a single framework. It suggests that the strong force, the weak force, and the electromagnetic force become one at very short distances.





Supersymmetry also naturally leads to a new dark matter particle that does not emit or absorb light, and can only be detected from its gravitational effects. Ordinary matter that is explained by the Standard Model makes up about 4 percent of the universe; dark matter comprises about 22 percent.

"We know from astrophysical observations that there is more matter than what we see," said Maldacena. "If we look at the sky, we see some galaxies sitting there in the sky, surrounded by what looks like the blackness of empty space. What we don't know is whether this dark matter particle will or will not be produced at the LHC."

In the last decade, astronomical observations of several kinds, particularly of distant supernova and the cosmic microwave background, also indicate the existence of what is known as dark energy, a uniform background field that makes up about 74 percent of the universe and is credited with accelerating the expansion of the universe. The presence of dark energy suggests a fundamental gap in our current understanding of the basic forces of nature.

"Space, time, and quantum mechanics framed the central dramas of the twentieth century, and really have taken us shockingly far. The story of the Higgs is the last example of how far they took us. But in a sense, the story of the Higgs is one of the last embers of the set of ideas that we dealt with and understood in the twentieth century," said Arkani-Hamed.

"Relativity and quantum mechanics—the picture of spacetime that Einstein gave us and quantum mechanics—are incredibly rigid and powerful. The next set of questions is: Where do these things come from? That's the one thing I didn't question. I just took spacetime and quantum mechanics and the rest of it followed. What is the deeper origin of spacetime and quantum mechanics? This is what you should ask your friendly neighborhood string theorist." ■

How Incompatible Worldviews Can Coexist

BY FREEMAN DYSON

John Brockman, founder and proprietor of the Edge website, asks a question every New Year and invites the public to answer it. THE EDGE QUESTION 2012 was, "What is your favorite deep, elegant, or beautiful explanation?" He got 150 answers that are published in a book, This Explains Everything *(Harper Collins, 2013). Here is my contribution.*

The situation that I am trying to explain is the existence side by side of two apparently incompatible pictures of the universe. One is the classical picture of our world as a collection of things and facts that we can see and feel, dominated by universal gravitation. The other is the quantum picture of atoms and radiation that behave in an unpredictable fashion, dominated by probabilities and uncertainties. Both pictures appear to be true, but the relationship between them is a mystery.

The orthodox view among physicists is that we must find a unified theory that includes both pictures as special cases. The unified theory must include a quantum theory of gravitation, so that particles called gravitons must exist, combining the properties of gravitation with quantum uncertainties.

Recommended Reading: Freeman Dyson was awarded the 2012 Henri Poincaré Prize at the International Mathematical Physics Congress in August. On this occasion, he delivered the lecture "Is a Graviton Detectable?" a PDF of which is available at http://publications.ias.edu/poincare2012/dyson.pdf.

LIGO LIVINGSTON OBSERVATORY

The LIGO Livingston Observatory in Louisiana

I am looking for a different explanation of the mystery. I ask the question, whether a graviton, if it exists, could conceivably be observed. I do not know the answer to this question, but I have one piece of evidence that the answer may be no. The evidence is the behavior of one piece of apparatus, the gravitational wave detector called LIGO that is now operating in Louisiana and in Washington State. The way LIGO works is to measure very accurately the distance between two mirrors by bouncing light from one to the other. When a gravitational wave comes by, the distance between the two mirrors will change very slightly. Because of ambient and instrumental noise, the actual LIGO detectors can only detect waves far stronger than a single graviton. But even in a totally quiet universe, I can answer the question, whether an ideal LIGO detector could detect a single graviton. The answer is no. In a quiet universe, the limit to the accuracy of measurement of distance is set by the quantum uncertainties in the positions of the mirrors. To make the quantum uncertainties small, the mirrors must be heavy. A simple calculation, based on the known laws of gravitation and quantum mechanics, leads to a striking result. To detect a single graviton with a LIGO apparatus, the mirrors must be exactly so heavy that they will attract each other with irresistible force and collapse into a black hole. In other words, nature herself forbids us to observe a single graviton with this kind of apparatus.

I propose as a hypothesis, based on this single thought-experiment, that single gravitons may be unobservable by any conceivable apparatus.

If this hypothesis were true, it would imply that theories of quantum gravity are untestable and scientifically meaningless. The classical universe and the quantum universe could then live together in peaceful coexistence. No incompatibility between the two pictures could ever be demonstrated. Both pictures of the universe could be true, and the search for a unified theory could turn out to be an illusion. ■

Freeman Dyson, Professor Emeritus in the School of Natural Sciences, first came to the Institute as a Member in 1948 and was appointed a Professor in 1953. His work on quantum electrodynamics marked an epoch in physics. The techniques he used form the foundation for most modern theoretical work in elementary particle physics and the quantum many-body problem. He has made highly original and important contributions to an astonishing range of topics, from number theory to adaptive optics.

conjecture. He explained that the zeros tend to repel between neighboring levels. At teatime, Montgomery mentioned his result to Freeman Dyson, Professor in the School of Natural Sciences.

In the 1960s, Dyson had worked on random matrix theory, which was proposed by physicist Eugene Wigner in 1951 to describe nuclear physics. The quantum mechanics of a heavy nucleus is complex and poorly understood. Wigner made a bold conjecture that the statistics of the energy levels could be captured by random matrices. Because of Dyson's work on random matrices, the distribution or the statistical behavior of the eigenvalues of these matrices has been understood since the 1960s.

Dyson immediately saw that the statistical distribution found by Montgomery appeared to be the same as the pair correlation distribution for the eigenvalues of a random Hermitian matrix that he had discovered a decade earlier. "His result was the same as mine. They were coming from completely different directions and you get the same answer," says Dyson. "It shows that there is a lot there that we don't understand, and when we do understand it, it will probably be obvious. But at the moment, it is just a miracle."

The unexpected discovery by Montgomery and Dyson at teatime in the 1970s opened a tantalizing connection between prime numbers and mathematical physics that remains strange and mysterious today. Prime numbers are the building blocks of all numbers and have been studied for more than two thousand years, beginning with the ancient Greeks, who proved that there are infinitely many primes and that they are irregularly spaced.

More than forty years after the teatime conversation between Dyson and Montgomery, the answer to the question of why the same laws of distribution seem to govern the zeros of the Riemann zeta function and the eigenvalues of random matrices remains elusive, but the hunt for an explanation has prompted active research at the intersection of number theory, mathematical physics, probability, and statistics. The search is producing a much better understanding of zeta functions, prime numbers, and random matrices from a variety of angles, including analyzing various systems to see if they reflect Wigner's prediction that the energy levels of large complex quantum systems exhibit a universal statistical behavior, a delicate balance between chaos and order defined by a precise formula.

Wigner's universality conjecture is somewhat analogous with the classical central limit theorem of probability theory, which explains why many distributions in nature tend to be close to the normal distribution of the Gaussian bell curve. The British polymath Sir Francis Galton described the central limit theorem as:

"I know of scarcely anything so apt to impress the imagination as the wonderful form of cosmic order expressed by the 'Law of Frequency of Error.' The law would have been personified by the Greeks and deified, if they had known of it. It reigns with serenity and in complete self-effacement, amidst the wildest confusion. The huger the mob, and the greater the apparent anarchy, the more perfect is its sway. It is the supreme law of Unreason. Whenever a large sample of chaotic elements are taken in hand and marshaled in the order of their magnitude, an unsuspected and most beautiful form of regularity proves to have been latent all along."

For centuries, probability theory has been used to model uncorrelated or weakly correlated systems. There is strong evidence that random matrix statistics plays a similar fundamental role for complicated correlated systems, among them the energy levels of the uranium nucleus, the zeros of the zeta function, and the spacing pattern of a decentralized bus system in the city of Cuernavaca, Mexico, which two physicists, Milan Krbálek and Petr Šeba, studied in the late 1990s. The bus system had no central authority or timetables to govern the arrivals and departures of the buses, which were individually owned by the drivers. In order to maximize their incomes, the drivers adjusted their speeds based on information obtained by bystanders about the departure times of the buses in front of them. Krbalek and Seba recorded the actual departure times of the buses at various stops and found that the spacings between buses match the statistical behavior found in random matrix theory.

According to Percy Deift (frequent Member in the School), "The list of such problems is varied, long, and growing, and points to the emergence of what one might call 'macroscopic mathematics.'" Just as physicists discern physical laws from the emergence of universal behavior in macroscopic systems, Deift observes, mathematicians are beginning to study the universality of a wide variety of mathematical problems. The widespread phenomenon, in which a whole class of seemingly unrelated problems or physical situations gives rise to the same statistical histogram, is being examined for insights that it might provide about various chaotic systems in the world around us.

"There are lots of deterministic things that behave chaotically," says Thomas Spencer, Professor in the School of Mathematics. "In general, that is a very hard thing to understand. Even the zeros of the Riemann zeta function, which are given by a formula, behave chaotically. Prime numbers behave chaotically. We don't understand why they do, and we would like to understand to what extent they do. What is amazing is that we can describe these characteristics in terms of random matrices to some extent."

In the mid-nineteenth century, mathematicians began to focus on conceptual properties rather than formulas and on understanding abstract concepts and relationships rather than calculation. Bernhard Riemann was a champion of the subject that was invented around that time called complex analysis. He explained that if you want to understand a complex analytic function—which is a rule relating complex numbers—you need to understand the locations of its zeros.

The zeta function was discovered by Leonhard Euler in the eighteenth century. Euler defined the function and showed that it has a deep and profound connection with the pattern of the primes. Riemann, after whom the zeta function is named (you don't have to be the first to study an object in mathematics in order to get it named after you), wrote about the zeta function and his related hypothesis in his memoir published in 1859—his only paper on the zeta function. Riemann's zeta function and other zeta functions similar to it known as L-functions (which came out of Lejeune Dirichlet's study of prime numbers in 1836) appear in number theory, the theory of dynamical systems, geometry, function theory, and physics. In his memoir, Riemann was trying to explain how to obtain an exact simple analytical formula for counting the number of primes up to a given limit.

"The failure of the Riemann Hypothesis would create havoc in the distribution of prime numbers," writes Enrico Bombieri, Professor Emeritus in the School, in the official problem description on the website of the Clay Mathematics Institute where it is listed as one of the Millennium Problems worth $1 million to any individual who can solve it. "This fact alone singles out the Riemann Hypothesis as the main open question of prime number theory."

The late Atle Selberg was an authority on the Riemann Hypothesis and developed many tools that allow mathematicians to go around it. "There have probably been very few attempts at proving the Riemann Hypothesis," said Selberg, "because, simply, no one has had any really good idea for how to go about it." Bombieri thinks Selberg may have meant to include "good" in his statement (as in "very few good attempts") in light of the numerous efforts that Bombieri receives from amateur mathematicians and physicists. "From time to time," says Bombieri. "I also receive crank mail from amateur mathematicians who think that they have disproved the Riemann Hypothesis."

In his memoir, Riemann gave a hint that he had computed the first few zeros. "Certainly, it is desirable to have a rigorous proof of this," wrote Riemann. "I have put aside this research for the time being after some fleeting superficial attempts, because it is not immediately needed for the sequel of my investigation." When his notes were reviewed by the late Carl Ludwig Siegel (Member and Professor at the Institute in the 1940s) about seventy years after Riemann's death, it was confirmed that before making his conjecture, Riemann had checked by hand that the first few zeros all lie on the critical line. With one of the earliest computers, Alan Turing computed the first one thousand zeros of the Riemann zeta function. Today, the hypothesis has been confirmed into the trillions of zeros.

"The Riemann zeta function remains one of the mysteries of modern mathematics. It is a function that we understand a lot about except for the most important question," says Peter Sarnak, Professor in the School of Mathematics. "It connects the theory of prime numbers, or encodes deep information about the theory of prime numbers, with the zeros. It controls the prime numbers in a way that nothing else we know does. While understanding prime numbers is an important problem, it is the generalizations of the Riemann zeta function and the objects associated with these that make it more significant."

Generalizations are extensions of a mathematical problem in an analogous, less-specific setting. Trying to prove the Riemann Hypothesis has produced answers to complicated questions with deep and extensive reach into many diverse areas of mathematics and physics. The Riemann Hypothesis and its generalizations have "analogues that are true all over the show," says Sarnak. "There is no question about its universal truth for all zeta functions that appear in the world. Its importance is amplified in that there are hundreds of theorems that say if the Riemann Hypothesis is true, or some generalization of it, then the following is true, and the following can be stunning. And most of these consequences are still not known, although many have been proven without proving the Riemann Hypothesis. So it allows you to get where you want to go quite quickly, and since we haven't been able to solve this problem, we find very complicated substitutes. In fact, if anybody proved this Riemann Hypothesis and these generalizations, you could throw away a number of books and many papers in libraries, which are there primarily to sidestep not knowing it."

For many years there was no proof of the prime number theorem without using Riemann's zeta function. One of the great achievements in 1948 took place at the Institute when Selberg and Paul Erdös (Member, 1938–40) gave an elementary proof of the prime number theorem without using the Riemann zeta function. "Some people naively thought there was no elementary proof," says Sarnak. "And there was a further hope that once you gave an elementary proof of the theorem it might give a better viewpoint on the Riemann Hypothesis, but that hasn't materialized yet."

When asked what would be the first thing he would do if he were brought to life again after five hundred years, David Hilbert, who with George Pólya proposed looking for a quantum mechanical system with eigenvalues given by the Riemann zeta-function zeros, replied, "I would ask whether the Riemann Hypothesis has been proved." André Weil, late Professor in the School of Mathematics, put a tremendous effort into trying to solve the problem later in his life. "In the past it sometimes occurred to me that if I could prove the Riemann Hypothesis, which was formulated in 1859, I would keep it secret in order to be able to reveal it only on the occasion of its centenary in 1959," said Weil in a 1979 interview. "Since 1959, I have felt that I am quite far from it; I have gradually given up, not without regret."

In 1941, Weil proved the analogue of the Riemann Hypothesis for all one-variable function fields over finite fields, the focus of his work while in a prison in Rouen for, in his words, "having a disagreement with the French authorities on my military 'obligations.'" Weil introduced new geometric points of view that allow the translation

(Continued on page 9)

of the problem to one in algebraic geometry. In 1973, Pierre Deligne used Alexander Grothendieck's cohomology theory, a tool that linearized the problem, to prove the Riemann Hypothesis for the zeta functions of complete nonsingular projective varieties over finite fields of any dimension. (For this work and other seminal contributions, Deligne, Professor Emeritus in the School of Mathematics, has been awarded the 2013 Abel Prize of the Norwegian Academy of Science and Letters; see article, page 3).

The function field analogue, where Weil and Deligne achieved their results, realizes the zeros as the eigenvalues of a matrix. "What is lacking in the case of the Riemann zeta function is an eigenvalue interpretation of the zeros that is useful," says Sarnak. "From the data, you have this remnant of a real object that you want to resurrect. Before you can start to do that, the first thing you need to know is, is it really coming from such and such an object? Are there some good tests or signatures for that?"

Quantum mechanics is a linear algebraic interpretation of mechanics in which the energy levels of quantum systems correspond to eigenvalues of matrices. It might provide a mathematical tool for using linear algebra to prove the Riemann Hypothesis if, as it appears, the zeros of the Riemann zeta function are behaving like eigenvalues of a matrix.

More than sixty years ago, Wigner was led to ask: If you take a random matrix, what do its eigenvalues look like? Would they look different if you chose the numbers randomly? It turns out that if you choose a matrix at random and look at its eigenvalues, you get a very different behavior than if you choose the numbers at random directly. What the eigenvalues look like became an interesting subject. This was the beginnings of what became random matrix theory—a subject in the theory of probability and linear algebra.

Dyson worked vigorously on random matrix theory for about ten years, roughly from 1962 to 1972, mostly in collaboration with Madan Mehta (Member, 1962–63). In the theory of random matrices, Dyson and Mehta identified three types of matrix ensembles with different correlations: Gaussian orthogonal ensemble (time reversal invariant and integer spin with weakest repulsion between neighboring levels), Gaussian unitary ensemble (no time reversal invariance with medium repulsion), and Gaussian symplectic ensemble (time reversal invariant with half integer spin and strongest repulsion). The ensembles are abbreviated as GOE, GUE, and GSE, respectively. In 1989, Andrew Odlyzko (Member, 1983–84) computed eight million zeros of the Riemann zeta function near to zero number 10^{20} and computed their pair-correlation numerically in a deep and very thorough investigation that confirmed the GUE connection.

When Sarnak was a graduate student at Stanford University, Paul Cohen (Member, 1959–61, 67), pointed him to Montgomery's work on the pair-correlation of the zeros of zeta and its connection to random matrix theory, and asked, why is it so? Sarnak's efforts to try to answer that question began with a paper with Zeev Rudnick (Member, 2008–10) on the higher correlations for zeros of the zeta function and led eventually to his extension of Montgomery's work. In the 1990s, Sarnak and his collaborator Nick Katz (frequent Member since 1991) brought techniques from physics and geometry into the function field setting of Deligne's proof and found that not only the pair-correlation function but all the many-level correlation functions of the zeta-function zeros agree with those of the GUE ensemble. They used techniques of mathematical physics, particularly those of Michel Gaudin, who calculated the distribution of the spacings between nearest-neighbor eigenvalues in 1961, to explain the phenomenon and the symmetry types.

The way Deligne proved the Riemann Hypothesis in general in the function field setting was not by looking at one zeta function at a time. Zeta functions can be collected into families, and with each family, you can ask subtle questions about the distribution of their zeros. Different families produce different distributions, in each of which the spacing correlation is universal, corresponding to random matrix theory. Central to this study is a group—the monodromy group—associated with the family, which acts linearly on related spaces. Monodromy is the glue—a symmetry connected with the family, which marries the different members. Sarnak's former students, among them Michael Rubinstein (Member, 2009–10), verified numerically all the conjectures in the classical number theoretic setting that Katz and Sarnak put forward connected with this glue.

"Not only does there appear to be a matrix interpretation, but this glue that is so critical in the proof in the function field setting, is apparently present here too. We know that, we can see it, but we don't have the object yet," says Sarnak. "It has led to predictions and theorems because this glue controls much of what happens within a family. We know a bit about it without knowing its real source. But just knowing what we can prove about the glue is already enough to deduce some consequences of the Riemann Hypothesis in general, and hence to solve a number of problems."

Progress also has been made in using random matrix theory to further explore connections between prime numbers and quantum physics. The even "moments" of the zeta function on the critical line are notoriously difficult to compute and in particular the leading coefficient for their asymptotic behavior. The only known cases, dating from the 1920s, are the second and fourth moments for which the coefficients are 1 and 2. Brian Conrey and Amit Ghosh (frequent Members since the early 1980s) conjectured that the coefficient for the sixth moment is 42. Using random matrix theory, physicists Jon Keating and Nina Snaith of Bristol University confirmed this result and provided a formula to predict all the numbers in the sequence.

Universality of various matrix ensembles will be one of the major themes of the School's special year program on non-equilibrium dynamics and random matrices that Spencer will be running next year with Horng-Tzer Yau of Harvard University (Member, 1987–88, 2003) who will be the School's Distinguished Visiting Professor. Yau is the author, along with Laszlo Erdős and Benjamin Schlein, and, independently, Terence Tao (Visitor, 2005) and Van Vu (frequent Member since 1997), of a recent proof that states that the eigenvalue statistics of a matrix do not depend on the distribution of its elements as long as they are independent and have the same distribution.

By investigating the universality phenomenon in random matrices, mathematicians are trying to develop a better sense of what universality is, why it arises, and how it can be used. The principle of universality suggests this is an enormous class, according to Spencer, who works in supersymmetric statistical mechanics and quantum mechanics. Some statistical properties of the random matrices are known and understood and others are conjectural.

Spencer's interest in random matrix theory stems from his study of the quantum mechanics of an electron moving in a random environment, such as a crystalline lattice with random impurities. Following work done by physicist Philip Anderson on the electronic structure of magnetic and disordered systems, Spencer has been studying Anderson-like matrices that look very different from those of Wigner. In these matrices, the randomness is limited and confined. To understand the quantum excitations of the electrons, Spencer studies the statistical mechanics of supersymmetric spins on a lattice. Physicists Franz Wegner and Konstantin Efetov explained the relation between the energy levels of the electron and supersymmetric statistical mechanics in the early 1980s. In the language of statistical mechanics, the energy level spacing should match those of GUE or GOE at low temperatures in three dimensions when the spins are aligned or ordered.

"If randomness is present, we have a pretty good understanding of universality from the point of view of physics using supersymmetric statistical mechanics," says Spencer. "But for a purely deterministic system, we have a much poorer understanding of how Wigner-Dyson statistics will emerge."

Perhaps surprisingly, one of the forebears commonly credited with understanding universality, isn't rooting for it. "My main contribution was to find these three different classes. It was the opposite of universality, proving that the three types are really very different. My prejudice is the other way," says Dyson.

"There is this sort of religious belief in universality which I don't agree with, but certainly there is some evidence for it. The idea is if you prove something for a single example, then it is likely to hold for all kinds of things with the same structure. The behavior is universal. It is the same behavior for a big class of objects. You could say that I have a baby who is very bad tempered, so I assume that that is a universality class, that all babies have bad tempers, which of course is not a valid conclusion. *[Laughs]* So I would be skeptical about universality. Sometimes it works and sometimes it doesn't. It is a matter of picking your examples. You can always find examples that behave the same, and you find examples that behave differently. But I don't like to call it universal unless it really is true everywhere."

If universality doesn't explain the mysterious connection, why does the pair correlation of the zeros of the Riemann zeta match that of the eigenvalues of the GUE? "That's a good question," says Dyson, "but we don't know."

Dyson believes quasi-crystals, which he studied with Paul Steinhardt when Steinhardt was a Member in the School of Natural Sciences more than twenty years ago, could provide some clues for solving the Riemann Hypothesis, which would illuminate pathways in many directions including its connection to random matrix theory. "People thought there were only two kinds of matter—the kind that is ordered in perfect crystals and the kind that is disordered and just a jumble of atoms," says Dyson. "The quasi-crystal comes in between. It has long-range order, but it doesn't have a regular spacing. That was a big surprise. I spent a lot of time trying to understand it. There is still a lot more to be understood."

Dyson started out as a mathematician, as a student of Harold Davenport's, a mathematician known for his extensive work in number theory. Dyson also took classes from G. H. Hardy who proved that there are infinitely many zeros of the Riemann zeta function on the critical line. When Dyson addressed an audience at the Mathematical Sciences Research Institute in 2002, he challenged young mathematicians to study quasi-crystals. "Like every serious student of pure mathematics, when I was young, I had dreams of proving the Riemann Hypothesis. I had some vague ideas that I thought might lead to a proof, but never pursued them vigorously," Dyson told the audience. "In recent years, after the discovery of quasi-crystals, my ideas became a little less vague. I offer them here for the consideration of any young mathematician who has ambitions to win a Fields Medal."

Quasi-crystals were discovered in 1984 and exist in spaces of one, two, or three dimensions. Dyson suggests mathematicians obtain a complete enumeration and classification of all one-dimensional quasi-crystals, the most prevalent type, with the aim of identifying one with a spectrum that corresponds to the Riemann zeta function and one that corresponds to the L-functions that resemble the Riemann zeta function. If it can be proved that a one-dimensional quasi-crystal has properties that identify it with the zeros of the Riemann zeta function, then the Riemann Hypothesis will have been proved. "In one dimension, there is no symmetry, and you have an enormous variety of quasi-crystals which we have not ever classified," says Dyson. "There is a huge universe there we haven't explored. It could be a very deep part of mathematics once you get into it. It's a wild speculation that it could lead to the Riemann Hypothesis. But I think it's not completely crazy; it is certainly a possibility." ■

Memories and Reflections

BY NILS A. BAAS

I came to the Institute for the first time as a young researcher in 1972, and I immediately fell in love with the place. Why? Here was everything I wanted at the time. Freedom to do research, a Faculty of the highest quality, brilliant colleagues, and a wonderful social community. The great thing is that this has not changed. We have been back several times, and now we are enjoying it again.

The Institute is a great place for thinking, testing, and developing new ideas without disturbances. To me, it has always been the Mount Olympus of theoretical science. When I was a schoolboy, my two heroes were Niels Henrik Abel and Albert Einstein. Abel was born and grew up not very far from where I grew up in Norway, so there was a close connection. But Einstein was working at a place called the Institute for Advanced Study in faraway Princeton. Not in my wildest fantasies did I imagine that one day I would have the privilege of being a Member here.

ANDREA KANE

Nils A. Baas (right), a joint Member in the Schools of Mathematics and Natural Sciences, is a Professor at the Norwegian University of Science and Technology in Trondheim.

Quality has always been an important issue at IAS. André Weil once defined first-rate intellects as individuals who try to surround themselves with people of higher intellect than themselves. Then he paused for a while—probably thinking of himself—and added: "if possible!"

At IAS, I also met Atle Selberg for the first time. Being fellow Norwegians, we soon became very close friends. Selberg always preferred to work alone at his own pace and said that he found talking to other mathematicians disturbing for his own thinking. But he also admitted the importance of being at a place like IAS. In Norway, he always worked in solitude. At the Institute, he was exposed to new ideas and mathematics that paved the way for his most famous result: the Selberg Trace Formula.

From the 1970s, I remember with great pleasure John Milnor's topology seminar, where all the young topologists had to speak. Milnor would sit there with books and notes, seemingly paying no attention to what happened on the blackboard. But, if something was wrong or unclear, he would suddenly look up and interrupt in a gentle way: "Do you mean the following . . . ?" By his question, he often solved the problem. I have never met anybody with such an ability to "X-ray" a situation and find the "fractures."

Milnor's office was legendary. Notes and books all over the place, multiple layers of papers on the desk, and he was writing on a board on his lap. Selberg once commented that Milnor could never leave IAS because he would be unable to clear his office. But Selberg was wrong; eventually, Milnor left for Stony Brook.

Over the last forty years, not much has changed at the Institute. The good things have been preserved and taken further. In the School of Mathematics, there are now more programs of specific activities that seem to be very successful, and Simonyi Hall has been added.

When I was here more than forty years ago, there was a brilliant geometer visiting as a Member. His name was James Simons. I think no one at the time anticipated the enormous success that he would have later on in finance. But what I find so admirable is the way in which he has been giving back to science, and has been instrumental in the creation of the Institute's Simons Center for Systems Biology.

I have had a longtime interest in biology. When on a short visit in 2005, I met Arnie Levine. I told him about some of my crazy ideas in biology and expected him to kick me out of his office. On the contrary, he asked me to come back and join his group. So I did in 2007, 2010, and now in 2013. Being a Member both in the School of Mathematics and the School of Natural Sciences has been a great experience and shows the opportunities at the Institute.

My field in mathematics is topology—the study of shapes. A goal for me has been to find structure in biology and in particular to understand the role of higher order structures. Why should this interest a molecular biologist like Arnie Levine?

In biology, as in many other sciences today, the amount of data is enormous. The problem is often to extract interesting and relevant information out of a large data set. That is a central problem of systems biology. Statistical methods play a vital role and have been quite successful.

Genomic data typically analyze a collection of samples—say tumors (typically 200 or more)—and record the intensity of their gene expressions (typically 20,000 genes). Hence we get a matrix of numbers. What can we use it for?

The present approach is to use clustering techniques to divide the samples into groups and hence obtain a classification. To some extent, this has been successful in cases like breast cancer. But better classifications and more detailed information are needed. Are there hidden structures in the biological information derived from cancers and from normal tissues and, if so, how do they differ?

From a topological point of view, dividing data into clusters is like dividing a space into connected components.

This is measured by the zero-dimensional homology group—hence zero-dimensional information. It is therefore natural to look for higher dimensional information and calculate higher dimensional homology groups. These would count the number of higher dimensional holes. But the data set is discrete and has no higher dimensional homology.

The idea is then to associate a combinatorial complex or "space" to the data set at various scales and then compute at all scales the part of the homology groups counting holes in higher dimensions—the Betti numbers. The result is a collection of "barcodes" describing the data. This method is called persistent homology.

The challenge is now to see what these barcodes and other topological invariants may tell us about the biology of the samples. For example, will many holes indicate a biological property such as the aggressiveness of a tumor?

This research is still in its infancy, but there are promising signs that it may lead to better biological understanding of the data. Only time will tell.

It may be that radically new mathematics has to be developed to understand the secrets of biology. The day may come when problems in biology give rise to entirely new mathematics as we have seen in physics. Then many more mathematicians will find it interesting to talk to biologists.

It seems to me that the Simons Center for Systems Biology at IAS is an ideal place for such new interdisciplinary investigations and developments. ■

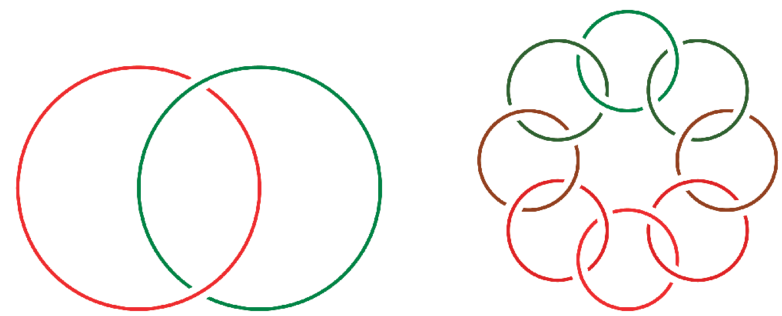
Links, Molecules, and Quantum States

BY NILS A. BAAS

For a long time time, I have had a profound interest in studying "higher order structures" of various kinds. What is a higher order object? I will not here attempt to give a definition, but rather illustrate by examples what I have in mind.

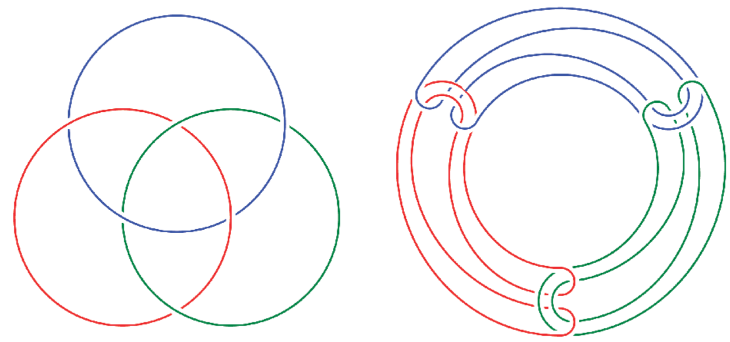
In topology, we study knots and links. A link is given by a collection of circles or rings embedded in three-dimensional space. If the link has just one ring, we call it a knot. There is a plethora of links, hence I have picked out special families in order to illustrate certain types of higher order structures.

Let us first look at three well-known links:



(a) Hopf link (b) Hopf-ring = ring of rings

FIGURE 1



Borromean rings to the left and Brunnian rings of type $1B(3)$ to the right

FIGURE 2

Definition. (i) A link consisting of n rings has the Brunnian property if and only if any sublink of $(n-1)$ rings is unlinked.

(ii) A link consisting of n rings has the Borromean property if and only if any two rings are unlinked.

For $n=3$, the two properties coincide as we see in Figure 2.

(Continued on page 11)

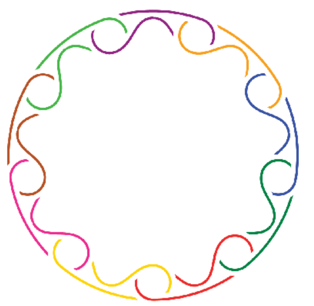
How do we describe such linkings? Staying on the rings, the topology is simple, but in the complement, it is complicated. Hence, we study the topology of the complement

$$K = \mathbb{R}^3 - \text{Link}.$$

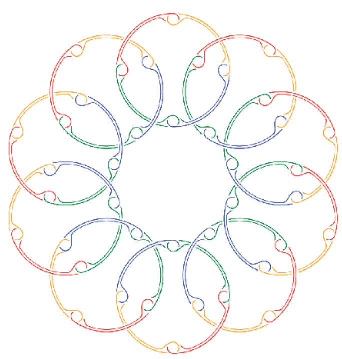
Hopf links are detected by cohomological cup products and Borromean rings by Massey products. In addition, other invariants like the Jones polynomials pick up linkings of this kind.

What about higher order links?

In Figure 3, we consider rings of rings based on the Hopf link:



(a) ring of rings (type $1H(9)$)

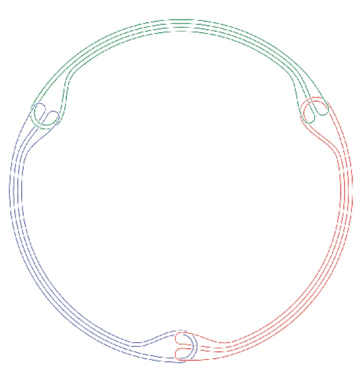


(b) ring of ring of rings (type $2H(4,10)$)

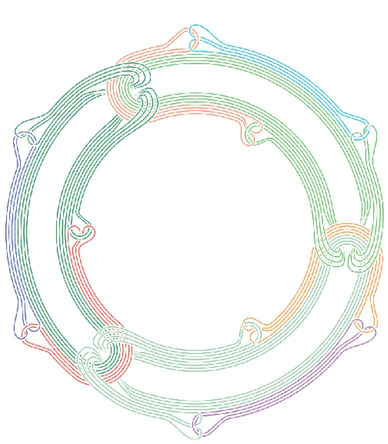
FIGURE 3

We call these Hopf rings of first and second order. This linking is detected by an extended version of Massey products.

Let us now build a family of Brunnian rings starting with a Brunnian ring as in Figure 4(a). We take three of these, bend them, and hook them up in a Brunnian way to a Brunnian ring of Brunnian rings—a second order Brunnian ring as in Figure 4(b).



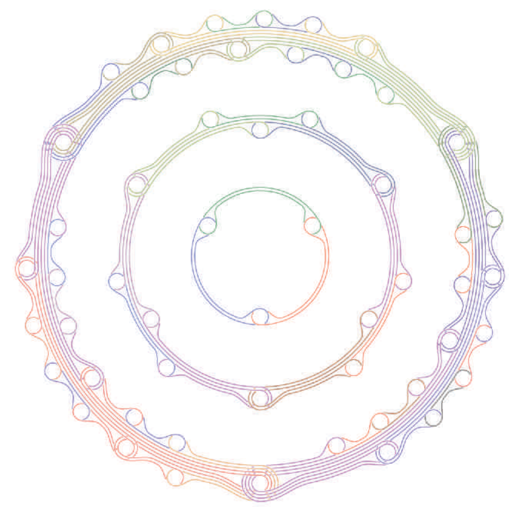
(a) Type $1B(3)$



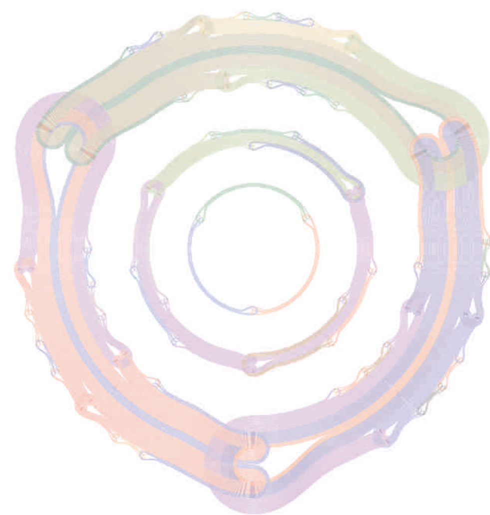
(b) Type $2B(3,3)$

FIGURE 4

This process can be iterated by taking second order rings and forming third order rings, etc. The number of rings at each level can vary. Hence we get a family of Brunnian rings n-$B(k_1,k_2,\ldots,k_n)$ which captures the idea of being of higher order. This family is a good guide for our intuition. In Figure 5, we show the lower stages of the Hopf-family and the Brunnian family. Good invariants are needed to describe efficiently this kind of higher order linking.



(a) Inner ring: $1H(3)$ Middle ring: $2H(3,3)$
Outer ring: $3H(3,3,3)$



(b) Inner ring: $1B(3)$ Middle ring: $2B(3,3)$
Outer ring: $3B(3,3,3)$

FIGURE 5

In synthetic chemistry, it has been a challenge to synthesize various knots and links. The first one to synthesize Borromean rings was Ned Seeman at New York University using DNA molecules. We have teamed up, and he is now working on the synthesis of higher order links—in particular, second order Brunnian rings. It will be interesting to see whether new material properties will appear.

In 1970, the Russian physicist V. Efimov predicted new counterintuitive quantum states where three particles are bound, but not two by two. This is quite analogous to the Borromean and Brunnian property. Experimentally, such states were not observed until 2006 in ultracold caesium gases.

This raises the following interesting question: Does there exist a family of quantum states analogous to the Brunnian family?

We know that this is the case at the bottom level, but what about higher up. Trimers exist, what about trimers of trimers? The question is wide open!

Independent of the role of these higher order links in mathematics, chemistry, and physics, they have an intrinsic beauty that everybody can enjoy.

Borromean rings have a long history. They appeared in old pieces of art in Afghanistan, in the form of triangles in Nordic mythology, and in the coat of arms of the Italian Borromeo family. In the Christian church, they have been used as a symbol of the Holy Trinity. ■

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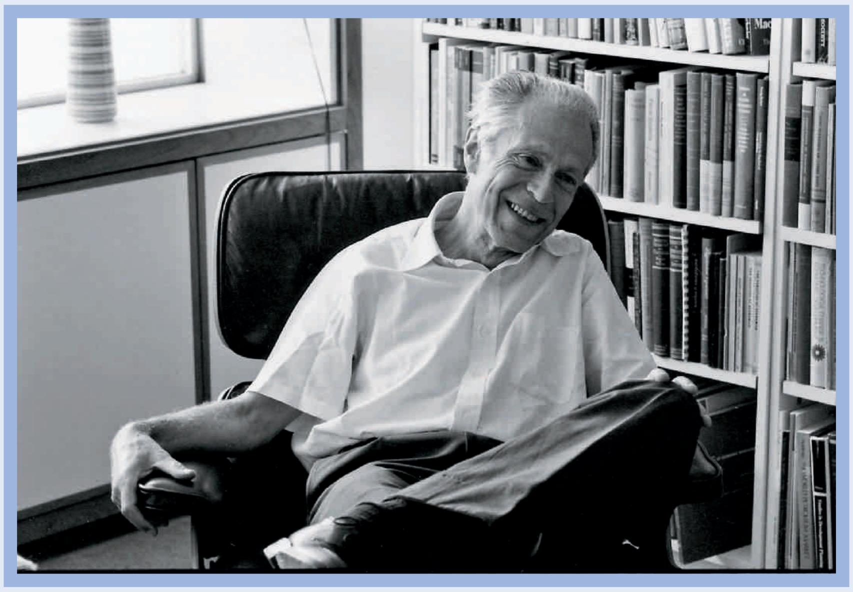
Albert O. Hirschman
1915–2012

Renowned social scientist Albert O. Hirschman, whose highly influential work in economics and politics in developing countries has had a profound impact on economic thought and practice in the United States and beyond, died at the age of 97 on December 10 at Greenwood House in Ewing Township, New Jersey. Hirschman was Professor Emeritus in the Institute's School of Social Science, where he had served on the Faculty since 1974.

“Albert Hirschman developed innovative methods for promoting economic and social growth through his study of the intellectual underpinnings of economic policies and political democracy,” said Robbert Dijkgraaf, Director and Leon Levy Professor at the Institute. “An impassioned observer who sought to understand the world as well as change it, Albert will be sorely missed by the Institute community and by the international community at large where his voice has influenced and guided advancement for more than half a century.”



HERMAN LANDSHOFF

Albert Hirschman in 1981 in his office at the Institute

Over the course of his long and extraordinarily productive career, Hirschman earned a reputation for progressive, lucid, and brilliantly argued contributions to economics, the history of ideas, and the social sciences. He explored a vast range of topics, inspired by the complexity of human behavior and social reality rather than by traditional economic models. He applied a subtle and iconoclastic perspective to reappraising conventional wisdom, resulting in original work that was a constant stimulus to critical thought in the social sciences. In a 1993 interview with Carmine Donzelli, Hirschman noted, “The idea of trespassing is basic to my thinking. Attempts to confine me to a specific area make me unhappy. When it seems that an idea can be verified in another field, then I am happy to venture in this direction. I believe this is a simple and useful way of discovering ‘related’ topics.”

Born in Berlin on April 7, 1915, Hirschman left Germany in 1933 for France, where he studied economics, finance, and accounting. In 1935, he received a one-year fellowship at the London School of Economics. From London he went to Barcelona to fight in the Spanish Civil War, saying, “I could not just sit and look on without doing anything.”

He completed his studies in Italy at the University of Trieste, where he received a doctorate in economics in 1938. Racial laws enacted by Mussolini compelled Hirschman to return to Paris, where he produced his first economic writings and reports, marking the beginning of a prolific publication record. In his numerous books and articles since that time, he continued to explore the complex relationships between economics, politics, social structures, values, and behavior.

Hirschman volunteered for service in the French Army and was enlisted in 1939. With the collapse of the French Army in 1940, he fled to the south of France. There he met Varian Fry, an American who had come to Marseille to organize a rescue operation to try to save the lives of endangered refugees, including Marc Chagall, Max Ernst, André Breton, and Marcel Duchamp. Fry needed a close assistant, and he found one in Hirschman, whom Fry dubbed “Beamish” for his unfailing optimism. Hirschman traded currency on the black market, obtained forged documents and passports, devised ways to transmit messages by concealing strips of paper in toothpaste tubes, arranged for ships to transport—often illegally—many of the refugees, and personally explored escape routes over the Pyrenees into Spain. Eventually, the police found Beamish's trail, so Hirschman joined the refugee flow across the mountains. By the time the operation closed down in September 1941, when the French expelled Varian Fry, his group had helped some 2,000 people escape from France. The United States government recognized the Varian Fry group in 1991 for its heroic accomplishments.

Hirschman immigrated to the United States in 1941 with the help of a Rockefeller Foundation fellowship at the University of California, Berkeley. At Berkeley, he met and married Sarah Chapro, a fellow European émigré who was earning her master's degree in French literature. In March 1943, Hirschman enlisted in the U.S. Army and was sent to North Africa and Italy as part of the Office of Strategic Services and served as an interpreter for a German general in one of the earliest World War II criminal trials. With the war's end, the Hirschmans settled in Washington, where Albert worked for the Federal Reserve Board on European reconstruction, focusing on new initiatives within the Marshall Plan agency.

In 1952, the Hirschmans moved to South America, where Albert worked as an economic adviser to the country of Colombia. The subsequent four years there inspired his vision of economic development as a sequential and unbalanced process. In Colombia, he encountered a major intellectual challenge: not so much the problem of poverty itself, but questions about the reasons for poverty and the search for strategies to diminish its effects. This led to Hirschman's growing realization that economics needed to draw on moral imperatives and goals as well as on a complex and ever-changing reality. Hirschman returned to the United States in 1956 and began his academic career, which included positions at Yale, Columbia, and Harvard universities. In 1974, he became a Professor at the Institute, where he joined Clifford Geertz in creating the School of Social Science. He became Professor Emeritus in 1985. Among his pioneering books are *The Strategy of Economic Development* (1958); *Journeys Toward Progress: Studies of Economic Policy-Making in Latin America* (1963); *Exit, Voice, and Loyalty: Responses to Decline in Firms, Organizations, and States* (1970); *The Passions and the Interests: Political Arguments for Capitalism before Its Triumph* (1977); and *The Rhetoric of Reaction: Perversity, Futility, Jeopardy* (1991). Throughout his career, he authored dozens of illuminating essays, which provided critical commentary on economic change and growth in Latin America as well as on the shifting landscape of the social sciences.

Recommended Reading: *Worldly Philosopher: The Odyssey of Albert O. Hirschman* (Princeton University Press, 2013) by Jeremy Adelman, Member (2001–02) in the School of Historical Studies

It was at the Institute that he and Professor Geertz created a unique forum for the social sciences. In seeking to bridge the divides between increasingly professionalized disciplines, they favored a more “interpretive style,” a term which eventually acquired multiple meanings—not all of them consistent with Hirschman and Geertz's original purpose to explore the interaction between culture, politics, and economics. “There is no doubt,” says Jeremy Adelman, Princeton University historian and author of a recent biography of Hirschman, “that Hirschman's time at the Institute allowed him to become one of the great sages of our times. His unusual background, combination of intellectual traditions, and ironic disposition were combined to yield some of the classic works of the social sciences.”

Joan Wallach Scott, Harold F. Linder Professor in the School of Social Science, added, “Albert's time at the Institute not only advanced his own work, but had a remarkable effect on the scholars who came into contact with him. His generosity, his wry humor and vivid intelligence, his gift for sociability, and his genuine interest in the thoughts of others inspired generations of social scientists to think outside the boundaries of the received wisdom in their fields.”

Hirschman was widely recognized for his work and was the recipient of many prizes and honors, including the Talcott Parsons Prize for Social Science, presented by the American Academy of Arts and Sciences in 1983; the Kalman H. Silvert Award of the Latin American Studies Association in 1986; the Toynbee Prize in 1997; the Thomas Jefferson Medal of the American Philosophical Society in 1998; and the Benjamin E. Lippincott Award of the American Political Science Association in 2003. In 2007, the Social Science Research Council established an annual prize in Hirschman's honor. The Global Development and Environment Institute at Tufts University selected Hirschman as a recipient of the 2013 Leontief Prize for Advancing the Frontiers of Economic Thought for his critical role in crossing disciplines to forge new theories and policies to promote international development. In honor of Hirschman's exceptional contributions to economic thought, the Institute created the Albert O. Hirschman Professorship in the School of Social Science in 1998.

Hirschman was a member of the American Academy of Arts and Sciences, the American Philosophical Society, and the National Academy of Sciences and was named a Distinguished Fellow of the American Economic Association. He was a foreign member of the Accademia Nazionale dei Lincei and a Corresponding Fellow of the British Academy. He received the Order of San Carlos from Colombia in 1995, the National Order of the Southern Cross from Brazil in 2000, conferred by his long-time friend and collaborator, President Fernando Henrique Cardoso, and the Order of Bernardo O'Higgins from Chile in 2005.

Hirschman is survived by his daughter, Katia Salomon, of Paris; two sons-in-law, Alain Salomon and Peter Gourevitch; four grandchildren, Lara Salomon Pawlicz, Grégoire Salomon, and Alex and Nick Hirschman Gourevitch; nine great-grandchildren, Hannah, Rebecca, Isaac, Eva, Rachel, Olivia, Ezra, Theodore, and Zackary; and a sister, Eva Monteforte, of Rome. He was predeceased by a daughter, Lisa Hirschman Gourevitch, in 1999, and by his wife of 70 years, Sarah Hirschman, founder of People & Stories/Gente y Cuentos, in January of 2012. ■

On March 24, a celebration of the life and work of Albert O. Hirschman was held at the Institute. Videos of the talks may be viewed at http://video.ias.edu/remembering-albert-o-hirschman-3-13, and the talks will be published as an upcoming Occasional Paper: www.sss.ias.edu/publications/occasional.

BY D. KOTSCHICK

In many different ways, 1953 was an exciting year. In February–March, at the Cavendish Lab in Cambridge, England, James Watson and Francis Crick discovered the structure of DNA molecules and its double-helix geometry. This discovery was announced in *Nature* in April and hit the news during the second half of May. Several newspaper articles in the English and American press at the time celebrated the work of Watson and Crick as closing in on the secret of life. This enthusiasm was vindicated by later developments, so that the publication of Watson and Crick's paper[1] is now regarded as one of the most important scientific events of the twentieth century.

At the same time, a British expedition was on the slopes of Mount Everest attempting the first climb to the top of the highest mountain on earth, which had, until then, defeated all challengers. The expedition set up base camp in March and then worked its way up the mountain. After a failed summit attempt by a different pair of climbers, Edmund Hillary and Tenzing Norgay finally conquered Mount Everest on May 29, 1953. News of their success reached the Western world on June 2 and was a front-page story. It so happened that June 2 was also Coronation Day in England, when Queen Elizabeth II was crowned after having ascended to the throne upon the death the previous year of her father, King George VI. The *New York Times* called the news of Hillary and Tenzing's exploit a "coronation gift."

In that spring of 1953, Friedrich Hirzebruch was hard at work at the Institute in Princeton. He had arrived from Germany the previous summer for what would become a two-year stay and had immediately immersed himself in learning sheaf theory, algebraic geometry, and characteristic classes under the guidance of Kunihiko Kodaira and Don Spencer of Princeton University. By the spring of 1953, Hirzebruch was trying to solve what he thought of as the Riemann-Roch problem: to formulate and prove a far-reaching generalization of the nineteenth-century Riemann-Roch theorem, extending it from algebraic curves to algebraic varieties of arbitrary dimensions. The setting was sheaf cohomology and the goal was to find a formula for certain Euler characteristics in sheaf cohomology in terms of Chern classes.

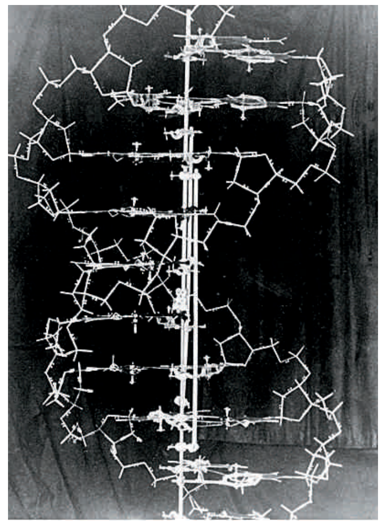
Just a couple of years earlier, in 1950, William Hodge had proved that the sum of all the Euler characteristics that Hirzebruch was looking at equals the signature of the underlying manifold. The signature is a simpler invariant than sheaf cohomology and makes sense for a manifold that need not be an algebraic variety. It had been introduced in this more general context by Hermann Weyl as early as 1923. Hirzebruch understood that if the purported Riemann-Roch theorem were true, then, by Hodge's theorem, the sum of all the expressions in Chern classes on the right-hand side would have to reduce to an expression in Pontryagin classes. This would give a formula identifying the signature of a manifold with an expression in its Pontryagin characteristic classes.

By May of 1953, Hirzebruch knew what this formula had to be, and he had verified it in many cases. He had thus arrived at conjecturing the so-called signature theorem. On Coronation Day, June 2, 1953, in the library of the Institute, Hirzebruch read the note by René Thom in the *Comptes Rendus* of the Paris Academy announcing his calculation of the oriented bordism ring (tensored with $\mathbb{Q}$). With this calculation in hand, the proof of the signature theorem was complete, since both sides are bordism-invariant and Hirzebruch had already verified the theorem for Thom's generators of the bordism ring. Even if Hirzebruch had been a subject of Queen Elizabeth II, rather than being German, I very much doubt that anyone would have considered the signature theorem a coronation gift.

D. Kotschick, Member in the School of Mathematics, is Professor of Mathematics at the Ludwig-Maximilians-Universität München. He works in geometry and topology, and is currently particularly interested in the topology of algebraic varieties. He first met Friedrich Hirzebruch when he was still a student, and has repeatedly drawn inspiration from Hirzebruch's work, and from the problems Hirzebruch formulated.

But then, unlike Hillary and Tenzing, Hirzebruch was

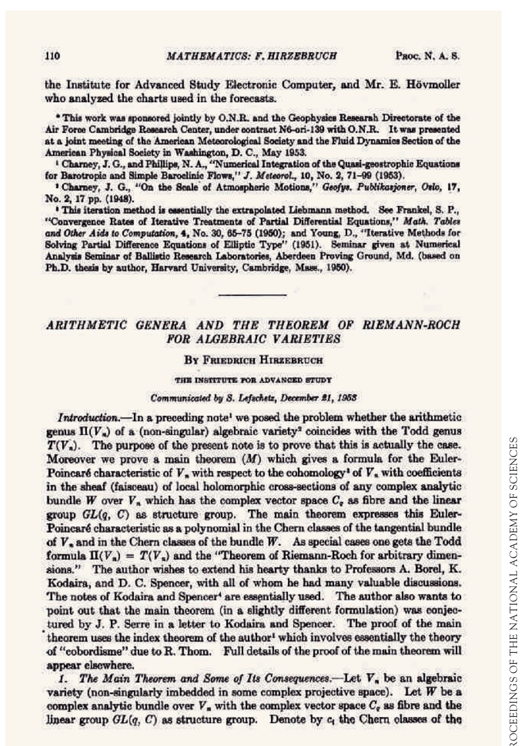
TIME LIFE



COLD SPRING HARBOR LABORATORY ARCHIVES

From left: The July 13, 1953, issue of LIFE Magazine, featuring Hillary and Tenzing's climb to the top of Mt. Everest; Watson and Crick's original model of the DNA double helix, displayed at the 1953 Cold Spring Harbor Symposium

not at the summit yet. Rather, the proof of the signature theorem announced in the *Proceedings of the National Academy of Sciences*[2] became his advanced base camp for the final push towards the general Riemann-Roch theorem. During that push, Kodaira shared with Hirzebruch a letter he had received from Jean-Pierre Serre, in which Serre proposed an even more general version of Riemann-Roch than Hirzebruch had envisaged. Serre had verified his conjecture in many cases, and Hirzebruch saw immediately that Serre's more general formulation



110 MATHEMATICS: F. HIRZEBRUCH PROC. N. A. S.

the Institute for Advanced Study Electronic Computer, and Mr. E. Hövmoller who analyzed the charts used in the forecasts.

* This work was sponsored jointly by O.N.R. and the Geophysics Researah Directorate of the Air Force Cambridge Research Center, under contract N6-ori-139 with O.N.R. It was presented at a joint meeting of the American Meteorological Society and the Fluid Dynamics Section of the American Physical Society in Washington, D. C., May 1953.

1 Charney, J. G., and Phillips, N. A., "Numerical Integration of the Quasi-geostrophic Equations for Barotropic and Simple Baroclinic Flows," *J. Meteorol.*, 10, No. 2, 71–99 (1953).

2 Charney, J. G., "On the Scale of Atmospheric Motions," *Geofys. Publikasjoner, Oslo*, 17, No. 2, 17 pp. (1948).

3 This iteration method is essentially the extrapolated Liebmann method. See Frankel, S. P., "Convergence Rates of Iterative Treatments of Partial Differential Equations," *Math. Tables and Other Aids to Computation*, 4, No. 30, 65–75 (1950); and Young, D., "Iterative Methods for Solving Partial Difference Equations of Elliptic Type" (1951). Seminar given at Numerical Analysis Seminar of Ballistic Research Laboratories, Aberdeen Proving Ground, Md. (based on Ph.D. thesis by author, Harvard University, Cambridge, Mass., 1950).

ARITHMETIC GENERA AND THE THEOREM OF RIEMANN-ROCH FOR ALGEBRAIC VARIETIES

BY FRIEDRICH HIRZEBRUCH

THE INSTITUTE FOR ADVANCED STUDY

Communicated by S. Lefschetz, December 21, 1953

Introduction.—In a preceding note[1] we posed the problem whether the arithmetic genus $\Pi(V_n)$ of a (non-singular) algebraic variety[2] coincides with the Todd genus $T(V_n)$. The purpose of the present note is to prove that this is actually the case. Moreover we prove a main theorem (M) which gives a formula for the Euler-Poincaré characteristic of V_n with respect to the cohomology[3] of V_n with coefficients in the sheaf (faisceau) of local holomorphic cross-sections of any complex analytic bundle W over V_n which has the complex vector space C_q as fibre and the linear group $GL(q, C)$ as structure group. The main theorem expresses this Euler-Poincaré characteristic as a polynomial in the Chern classes of the tangential bundle of V_n and in the Chern classes of the bundle W. As special cases one gets the Todd formula $\Pi(V_n) = T(V_n)$ and the "Theorem of Riemann-Roch for arbitrary dimensions." The author wishes to extend his hearty thanks to Professors A. Borel, K. Kodaira, and D. C. Spencer, with all of whom he had many valuable discussions. The notes of Kodaira and Spencer[4] are essentially used. The author also wants to point out that the main theorem (in a slightly different formulation) was conjectured by J. P. Serre in a letter to Kodaira and Spencer. The proof of the main theorem uses the index theorem of the author[1] which involves essentially the theory of "cobordisme" due to R. Thom. Full details of the proof of the main theorem will appear elsewhere.

1. The Main Theorem and Some of Its Consequences.—Let V_n be an algebraic variety (non-singularly imbedded in some complex projective space). Let W be a complex analytic bundle over V_n with the complex vector space C_q as fibre and the linear group $GL(q, C)$ as structure group. Denote by c_i the Chern classes of the

PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES

Friedrich Hirzebruch's 1954 paper (shown here), which announced the proof of what we now call the Hirzebruch-Riemann-Roch theorem, was written while he was a Member at the Institute. Hirzebruch's work at IAS in 1953 has had a profound influence on mathematics, and even on theoretical physics, over the last sixty years.

reduced to the special cases he himself had been focusing on by means of the splitting principle he had developed. Finally, around December 10, Hirzebruch completed the proof of what we now call the Hirzebruch-Riemann-Roch theorem. This proof, announced in *PNAS*[3] and submitted through Solomon Lefschetz of Princeton University on December 21, 1953, used a complicated induction procedure to ultimately reduce the general Riemann-Roch theorem to the signature theorem that Hirzebruch had proved six months earlier.

Hirzebruch's work at the Institute in 1953 has had a profound influence on mathematics, and even on theoretical physics, over the last sixty years. In 1956, John Milnor, then at Princeton University, used the signature theorem to prove the existence of exotic spheres, giving rise to the new field of differential topology. The Riemann-Roch theorem was soon generalized further by Alexander Grothendieck and became a cornerstone of the development of algebraic geometry. In 1962–63, the signature theorem and the Riemann-Roch theorem were the motivating examples that led Michael Atiyah and Isadore Singer to the formulation of their index theorem, which brought together previously unrelated areas of mathematics and later played an important role in the modern interactions between geometry and physics. The first proof of the index theorem closely followed Hirzebruch's approach to Riemann-Roch.

All these methods and results are ubiquitous in present-day mathematics. As just one example, consider the first application of gauge theory to four-dimensional topology, published by Simon Donaldson in 1983, exactly thirty years after the proof of the signature theorem. Donaldson's argument makes crucial use of the Atiyah-Singer index theorem and of the bordism-invariance of the signature, which was also crucial for Hirzebruch's proof of the signature theorem. Donaldson's breakthrough led to the discovery of exotic smooth structures on Euclidean four-space, one of the most startling events in differential topology since Milnor's discovery of exotic spheres. Nowadays, low-dimensional topology is dominated by theories that are outgrowths and variants of Donaldson theory.

The importance of Hirzebruch's work for mathematics is comparable to that of Watson and Crick's work for the life sciences. Both have transformed their respective fields, both have forged links between previously unrelated fields, and both have spawned new developments without which the modern scientific landscape would be unimaginable.

Neither Hirzebruch nor Watson and Crick worked in isolation. Like Hillary and Tenzing, whose achievement would not have been possible without the collaboration and support of many others sharing their goal—and sometimes competing to get there first—Watson and Crick's work would not have been possible without their interaction with Linus Pauling, Maurice Wilkins, Rosalind Franklin, and Raymond Gosling. In a similar vein, Hirzebruch's work would not have been possible without his interactions with Kodaira, Spencer, Thom, and Serre. However, Hirzebruch's work did not lead to a controversy parallel to the famous dispute arising from Watson and Crick's use of the X-ray data of Franklin and Gosling. This is not because mathematicians are not competitive—quite the opposite is true—but was probably due to Hirzebruch's generous personality and his always gracious acknowledgments of the contributions of others. All his life, until he passed away in May of 2012, Hirzebruch was on warm and friendly terms with his colleagues. He was forever grateful for the opportunity to come to the Institute and to have been welcomed by and to have collaborated with colleagues he respected and admired. ■

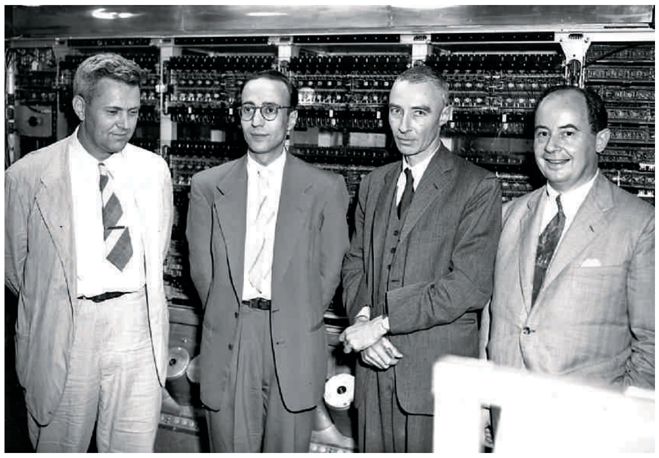
1. J. D. Watson and F. H. C. Crick, "Molecular Structure of Nucleic Acids: A Structure for Deoxyribose Nucleic Acid," *Nature*, 171 (1953): 737–38.
2. F. Hirzebruch, "On Steenrod's Reduced Powers, the Index of Inertia, and the Todd Genus," *Proceedings of the National Academy of Sciences*, 39 (1953): 951–56.
3. F. Hirzebruch, "Arithmetic Genera and the Theorem of Riemann-Roch for Algebraic Varieties," *Proceedings of the National Academy of Sciences*, 40 (1954): 110–14.

Julian Bigelow: Bridging Abstract Logic and Practical Machines

BY GEORGE DYSON

Julian Himely Bigelow, who joined the IAS Electronic Computer Project as Chief Engineer in March of 1946, was appointed to a Permanent Membership in the School of Mathematics in December 1950 and remained a Member of the School of Natural Sciences until his death in February 2003. It was Julian Bigelow who grasped John von Neumann's vision of a future transformed by digital computing and took the lead in its realization, using the analogue electronics available in postwar New Jersey at that time.

The result was a bridge we now take for granted between the world of abstract logic and the world of practical machines. "It was no coincidence that the stored program computer came to fruition about ten years after … [Emil] Post and [Alan] Turing set the framework for this kind of thinking," Bigelow later explained, adding that von Neumann "knew [Kurt] Gödel's work, Post's work, [Alonzo] Church's work very, very well … so that's how he knew that with these tools, and a fast method of doing it, you've got the universal tool."[1]



ALAN RICHARDS

Electronic Computer Project leaders with IAS Director J. Robert Oppenheimer (center right): from left, Julian Bigelow, Herman Goldstine, and John von Neumann

Julian Bigelow, the fourth of five siblings, was born in Nutley, New Jersey—forty-two miles from Princeton—on March 19, 1913. At the age of three, while staying with an aunt, "he found a screw driver, and removed all the door knobs and put them in a big pile, and it took him a really long time to put all these door knobs back."[2] He entered the Massachusetts Institute of Technology at the age of seventeen, delivering milk in a Model T Ford to pay for his tuition and graduating with a master's degree in electrical engineering in 1936.

During World War II, he collaborated with Norbert Wiener on anti-aircraft fire control, drafting a fifty-five-page letter to Warren Weaver, written between November 2 and December 2, 1941, that remains a masterpiece of clear thinking and exposition, reporting on progress toward the Wiener-Bigelow "debomber" so far.[3]

Although their effort was too late to affect the outcome of the war, it resulted in Wiener's seminal *Extrapolation, Interpolation, and Smoothing of Stationary Time Series, with Engineering Applications*, a classified report that influenced Claude Shannon's subsequent formulation of a general theory of information and paralleled the work of Andrey Kolmogorov, conducted independently in the Soviet Union at about the same time. "The transmission of a single fixed item of information is of no communicative value," Wiener explained in 1942. "We must have a repertory of possible messages, and over this repertory a measure determining the probability of these messages."[4] The Wiener-Bigelow collaboration also led to a landmark paper, "Behavior, Purpose and Teleology," popularizing the notion of negative feedback, where "signals from the goal are used to restrict outputs which would otherwise go beyond the goal," and prompting the formation (under von Neumann's auspices at the IAS, with the sponsorship of the Josiah Macy Jr. Foundation) of what would become known as the Cybernetics Group.[5]

In 1943, Bigelow was assigned to the National Defense Research Council Applied Mathematics Panel's Statistical Research Group at Columbia University, where he served for thirty-one months. Faced with problems from the reliability of munitions to optimum targeting of dive bombers, he continued to formulate the thinking about fault-tolerance and reliability that would characterize his design of the IAS machine—whose parallel, 40-bit architecture (and 24-microsecond memory access time) appeared to defy the laws of probability given the reliability of electronic components at that time.

It was Wiener, visiting with von Neumann at the Institute just after the end of the war, who recommended enlisting Bigelow. "We telephoned from Princeton to New York, and Bigelow agreed to come down in his car," Wiener recalls. "We waited till the appointed hour and no Bigelow was there. He hadn't come an hour later. Just as we were about to give up hope, we heard the puffing of a very decrepit vehicle. It was on the last possible explosion of a cylinder that he finally turned up with a car that would have died months ago in the hands of anything but so competent an engineer."[6]

Von Neumann had convinced IAS Director Frank Aydelotte to *allow* him to build a computer, but had not given enough thought to *where* he could build the computer. Until the materials to build a new building could be requisitioned (under postwar rationing) and the building completed (in January 1947), Bigelow and his growing crew were crammed into the basement of Fuld Hall. "There was no space for us, and so for the first five or six months, we were crowded into the boiler room with a few work benches we set out," Bigelow explains. "There was not even an office for me to go to and hide, and think about circuit logic, without having people walking over my desk and crawling all over me."[7]

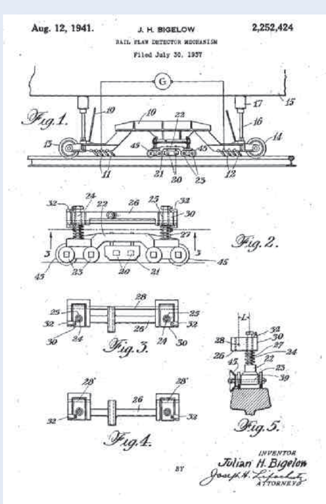
"The coming of six engineers with their assortment of oscilloscopes, soldering irons, and shop machinery was something of a shock," remembers Willis Ware, the fourth to join the group.[8] Bigelow had to fend off widespread resentment from the IAS community: over space and funding, over applied science encroaching on the domain of the pure, over salaries (engineers making much more than Members if much less than Faculty), and, to some extent, against a machine that many (including Einstein) already guessed would be used for nuclear weapons work. Bigelow described the situation as one of people "who had to think about what they were trying to do" objecting to people "who seemed to know what they were trying to do."[9]

Bigelow was "more physicist and theoretician than engineer," according to Willis Ware. "In modern parlance, what you'd say was: Julian was the architect of that machine." He was responsible for its progress, and, to the exasperation of Herman Goldstine, who had to intermediate with the project's government sponsors, he was responsible for many delays along the way. "The rate at which Julian could think, and the rate at which Julian could put ideas together was the rate at which the project went," adds Ware.[10]

Bigelow supervised not only the construction of the computer, but the construction of a housing project where the computer project personnel, and other sectors of the growing IAS population, could live. In August of 1946, a cluster of wood-frame apartment houses, built to

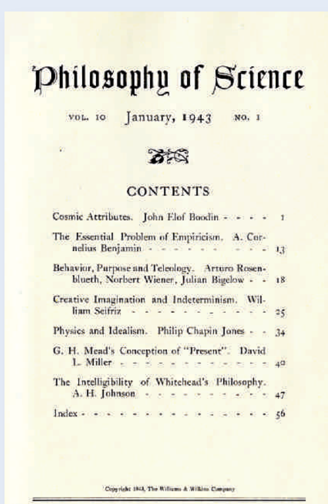
(Continued on page 15)

Bigelow Papers at IAS Document Nascent Fields of Computing and Cybernetics



GOOGLE PATENTS

▲ Bigelow's first job after graduation was with Sperry Corporation, where, according to an interview he gave in 1971, he "worked in the area of various kinds of instruments, particularly the instruments for recording the railroad track, etc., as detected by a car which traveled over the track and searched for flaws in the track itself and searched for balance in evenness of the track." He was awarded several patents for his rail flaw detector mechanism (pictured here).



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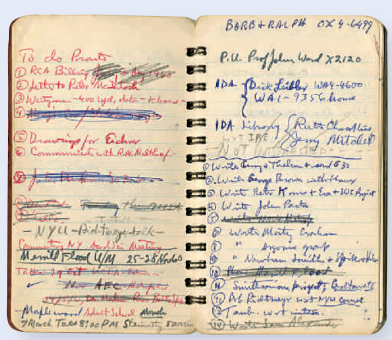
▲ Title page of the issue of *Philosophy of Science* in which "Behavior, Purpose and Teleology" first appeared in January 1943. Written by Norbert Wiener and Bigelow, along with neurophysiologist Arturo Rosenblueth, the paper was the basis for a meeting of the Teleological Society, an informal group that evolved into what were termed the Macy Conferences, a series of interdisciplinary meetings from 1946 to 1953 out of which came advances in systems theory, cognitive science, and cybernetics.



▲ Two pages from a notebook featuring one of Bigelow's many to-do lists, circa 1960

The Institute's Shelby White and Leon Levy Archives Center was gratified to receive the gift of Julian Bigelow's papers from his children Alice, Marc, and Nick, in the summer of 2012. Through correspondence, reports, schematics, technical literature, and other materials, Bigelow's papers document his participation in the nascent fields of computing and cybernetics, as well as his interactions with some of the leading technologically oriented minds of the twentieth century, including Norbert Wiener, John von Neumann, Warren McCulloch, and Gerald Estrin. These papers were among the many sources historian George Dyson drew upon in writing his acclaimed history of the Electronic Computer Project, *Turing's Cathedral: The Origins of the Digital Universe*. As the Electronic Computer Project is a frequent topic of inquiry for researchers in the archives, Bigelow's papers will enrich understanding of the project and his role in the revolution in computing and information processing that took place in the twentieth century.

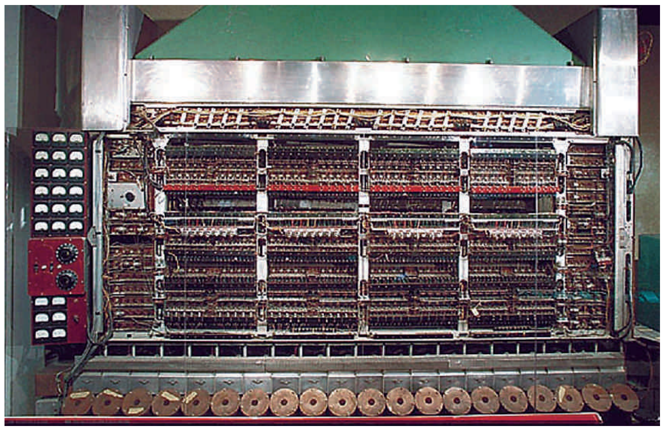
A preliminary finding aid to the papers is available online at http://library.ias.edu/finding-aids/bigelow. Interested researchers are welcome to contact the archives at archives@ias.edu for more information or to make an appointment to see the papers.

All images from the Institute for Advanced Study except where noted

BIGELOW *(Continued from page 14)*

house a wartime influx of workers at the Republic Steel Company's iron mines in Mineville, upstate New York, were put up for sale, and Aydelotte sent Bigelow up to Mineville the same day. "Thanks to the enterprise of Mr. Bigelow, we were able to buy eleven buildings, containing thirty-eight apartments of two and three bedrooms each," Aydelotte reported to the Trustees.[11] The buildings were partially dismantled, transported by rail to Princeton, and reassembled, with poured-concrete foundations, on Institute property—despite the complaints of nearby Princetonians who sought to halt the project "because of its deleterious effects upon the fashionable housing area which it will invade."[12] By February 1947, the first seventeen families, including the Bigelows, were occupying the new apartments, and more were moving in. "Since we have been here," Bigelow reported to Aydelotte, "we have come to know many of our neighbors quite well, not only those working in mathematics and physics, with whom we have much in common, but what is often more stimulating, we have met people working in other fields with experience and outlook different from our own."[13]

The reason the von Neumann computer project was so successful, and its design so widely replicated, was not just that all technical details of the new machine were disseminated and made freely available to both academia and industry, but that there was temporary housing available, adjacent to the computer building, where visitors could stay while running their problems and learning about the new machine. The result was in effect a School of Computer Science, although this designation did not exist. As Klári von Neumann explained it, "Johnny wanted to build a fast, electronic, completely automatic all-purpose computing machine which could answer as many questions as there were people who could think of asking them."[14]



THE SMITHSONIAN INSTITUTION

Beginning in 1958, Bigelow worked with the Smithsonian's Museum of Science and Technology to acquire early computing equipment and develop exhibits related to the history of computing. Through Bigelow's efforts and connections, parts from many early computers were preserved. The IAS machine (above) was moved to the Smithsonian Institution's collection in 1962.

In 1950, when von Neumann began lobbying for Permanent Memberships for Bigelow and Herman Goldstine in the School of Mathematics, he was attempting to secure a home for this work. "Bigelow's career has deviated from the conventional academic norm considerably," he argued. "This is, apart from economic reasons and the war, due to the fact that his field lies somewhere between a number of recognized scientific fields, but does not coincide with any of them."[15] The objective was not so much to build better or faster computers, a task already being taken up by industry, but, as Bigelow put it, to pursue "the relationship between logic, computability, perhaps machine languages, and the things that you can find out scientifically, now that this tool is available."[16] Digital computing "would cleanse and solve areas of obscurity and debate that had piled up for decades," Bigelow believed. "Those who really understood what they were trying to do would be able to express their ideas as coded instructions … and find answers and demonstrate explicitly by numerical experiments. The process would advance and solidify knowledge and tend to keep men honest."[17]

"The reason von Neumann made Goldstine and me Permanent Members," Bigelow explains, "was that he wanted to be sure that two or three people whose talent he respected would be around no matter what happened, for this effort." Von Neumann was less interested in building computers, and more interested in what computers could do. "He wanted mathematical biology, he wanted mathematical astronomy, and he wanted earth sciences," Bigelow recalled in 1971. "We would have the greatest school of applied science in the world. We could show the theoreticians that we could find out the answer to their number theoretic problems, their problems in physics, their problems in solid state, and their problems in mathematical economics. We would do planning, we would do things that would be known for centuries."[18]

And indeed they did. ■

George Dyson is the author of Turing's Cathedral: The Origins of the Digital Universe *(Pantheon, 2012), a history of the Electronic Computer Project, which he began writing while a Director's Visitor (2002–03) at the Institute.*

1 Julian Bigelow, interview with Nancy Stern, August 12, 1980, Charles Babbage Institute Oral History Series OH3.

2 Alice Bigelow, interview with George Dyson, May 24, 2009.

3 Julian Bigelow to Warren Weaver, December 2, 1941. A carbon copy of this letter survives among the papers that the Bigelow family has donated to the IAS archives this year.

4 Norbert Wiener, *Extrapolation, Interpolation, and Smoothing of Stationary Time Series, with Engineering Applications*, classified report to the National Defense Research Committee, February 1, 1942 (declassified edition, Boston: MIT Press, 1949), 2.

5 Julian Bigelow, Arturo Rosenblueth, and Norbert Wiener, "Behavior, Purpose and Teleology," *Philosophy of Science* 10, no. 1 (1943): 9, 23–24.

6 Norbert Wiener, *I am a Mathematician* (New York: Doubleday, 1956), 243.

7 Julian Bigelow, interview with Richard R. Mertz, January 20, 1971, Computer Oral History Collection, Archives Center, National Museum of American History.

8 Willis H. Ware, *The History and Development of the Electronic Computer Project at the Institute for Advanced Study*, RAND Corporation memorandum P-377, March 10, 1953, 8.

9 Julian Bigelow, interview with Richard R. Mertz, January 20, 1971.

10 Willis H. Ware, interview with Nancy Stern, January 19, 1981, Charles Babbage Institute Oral History Series OH37.

11 Frank Aydelotte, "Report of the Director," October 18, 1946.

12 Stanley C. Smoyer, memorandum to the Trustees, August 7, 1946.

13 Julian Bigelow to Frank Aydelotte, July 3, 1947.

14 Klára von Neumann, "The Computer," unpublished manuscript, ca. 1963.

15 Biographical background on J. H. Bigelow, November 14, 1950.

16 Julian Bigelow, interview with Richard R. Mertz, January 20, 1971.

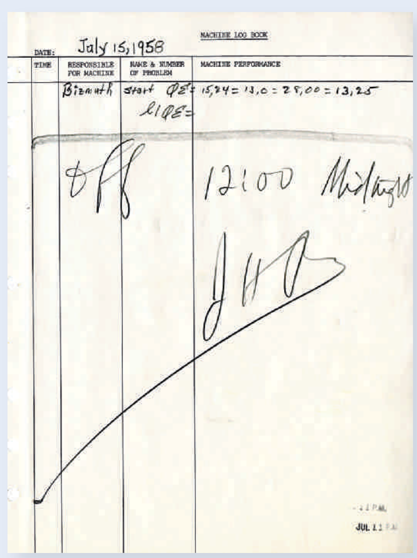
17 Julian Bigelow, "Computer Development at the Institute for Advanced Study," in Nicholas Metropolis, J. Howlett, and Gian-Carlo Rota, eds., *A History of Computing in the Twentieth Century* (New York: Academic Press, 1980), 291.

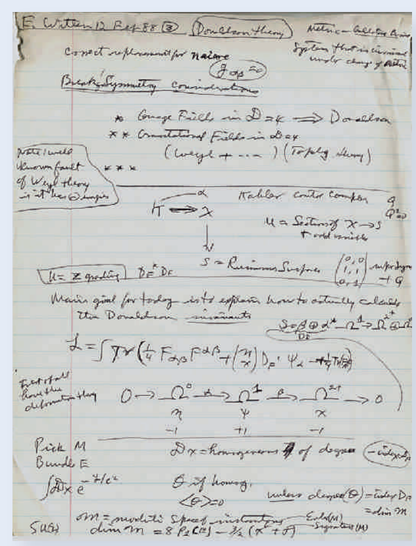
18 Julian Bigelow, interview with Richard R. Mertz, January 20, 1971.

▼ "Orders" note in Bigelow's hand—George Dyson identifies this as a command line, pointing out that the use of "bd" for binary digit dates it to the beginning of the project, before the abbreviation "bit" came into common usage. Bigelow's job, according to Dyson, was to take the logical design as laid out in the abstract by von Neumann and coax it to life using the electronics available in 1946.

Final entry in operations log book for the ECP, ► signed by Bigelow. From George Dyson's *Turing's Cathedral*:

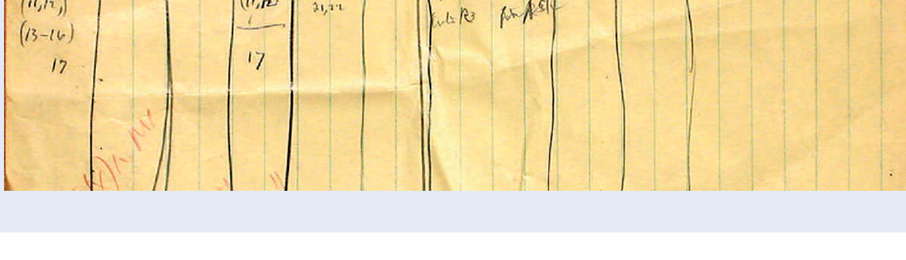
> At exactly midnight on July 15, 1958, in the machine room at the end of Olden Lane, Julian Bigelow turned off the master control, shut down the power supplies, picked up a blunt No. 2 pencil, and made the following entry in the machine log: "Off—12:00 Midnight—JHB." Knowing there would be no log entries to follow, he extended his signature diagonally across the rest of the page.





▲

Bigelow's notes from a seminar given by Edward Witten in February 1988. Bigelow was present for much of the Institute's history; during his time at the Institute, he had the opportunity to experience the tenures of six of its nine Directors, witness the establishment of three of its four Schools, and survey the construction of all of its academic buildings with the exception of Fuld Hall and its wings and the extension to Bloomberg Hall. There are few people in the history of the Institute with a longer continuous tenure. Well into his 70s, Bigelow was still a regular attendee of weekly seminars in the Schools of Natural Sciences and Mathematics, where he took extensive notes. As his sister Joan noted in a 1986 letter to Bigelow, access to the intellectual stimulation provided by the seminars at the Institute was essential to his well being.



especially social movements, can use their deliberate and disciplined entrance into mass-mediated public discourse as a resource that can make them equal to those who already hold the balance of access, money, and official position, the campaign was a powerful allegory. In the early days of the campaign for the White House, common wisdom held that Clinton would be the inevitable Democratic nominee. She was politically experienced, talented, well resourced, and she represented one of the most powerful Democratic families in the country. Barack Obama, who had made a splash at the 2004 Democratic National Convention with a keynote speech that was much more memorable than that of the presidential nominee, was generally regarded as promising, but too green to eclipse the Clinton juggernaut.

However, there was one thing that everyone acknowledged: the fresh-faced young man could *speak*. The organizational innovation and discipline of the Obama campaign, rooted in the community-organizing philosophy of Saul Alinsky, was essential to the eventual success of his campaign. Innovations in mobilization techniques, fundraising, and direct constituent communication techniques would be oft noted in election postmortems, but what distinguished the candidate in the popular political imagination, and what made his candidacy credible in those early days of campaign 2008, was the way he could turn a phrase.

Barack Obama is a rhetorician whose dominant style of argument is by a mode that Aristotle dubbed *ethos*, or character. Argument by *ethos* requires that the speaker be able to present themselves as "worthy of credence," something that a rhetor can show by demonstrating that they have "practical wisdom," "virtue," and "goodwill." Argument by *ethos* is both the most difficult of the persuasive modes of speech (which include argument by *logos*, or logic, and argument by *pathos*, or emotion) and the most powerful. This is because argument by *ethos* requires that a person be able to create a perception of their character in speech, separate from any assumptions based on ascriptive characteristics or prior assessment of deeds. If persuasion by *ethos* is successful, then the rhetor is able to create in the audience a "disposition toward belief" in the character of the speaker, a disposition that may exceed belief in the subject spoken about.

Social movements that seek to introduce new issues on the policy agenda can also benefit from crafting a perception of their character in public discourse. They can use rhetoric as a political resource that can earn them the public authority to challenge powerful opponents, both in bursts of direct legislative conflict and during the pursuit of long-range political goals. In my research comparing the successes of the contemporary marriage-equality and living-wage movements, I have found that creating a recognizable and persuasive argument in popular public discourse on the virtues of movement goals can be even more determinative of long-term and durable political change than discrete policy wins. For example, until 2012, the marriage-equality movement had been subject to one legislative defeat after another. Thirty-three states passed constitutional amendments to ban same-sex marriage, and every time the issue was put on a ballot initiative, it lost. Still, while the movement was losing policy fights, it was winning the rhetorical war. Movement leaders deliberately worked to shift the domain of the gay marriage debate from the focus on personal difference to a focus on political equality, all the while keeping the issue front and center on the political agenda, even when they were taking a policy beating. The living-wage movement, on the other hand, built an incredible network of organizations at municipal and state levels, allowing it to win the passage of over 120 new minimum wage ordinances across the country, but remained largely absent from the national political agenda and nearly invisible in popular public discourse. The result has been, according to sociologist Stephanie Luce, that after living wage ordinances are passed they are at high risk for going unimplemented. This is because small changes in the arrangements of local power can nullify the power brought to bear during legislative fights. My theory is that this counterintuitive result is due to the absence of a generalized public discourse on the topic. Such discourses create awareness and direct attention to new issues, ensuring that they remain on the public agenda, forcing officials to account for their positions (whether for or against). The public gaze, which is focused by political discourse, keeps pressure on elected officials, which helps keep them accountable. This kind of attention does not ensure victory for political challengers, especially in the short term, but it does prevent their issues from slipping into obscurity, where hard-won legislative victories can turn out to be pyrrhic.

Candidate Obama seemed to understand what a powerful political resource rhetoric can be for political underdogs. He was able to demonstrate his own practical wisdom, virtue, and goodwill with a rhetoric that came across as sincere, in part, because it externalized those qualities. In the 119 unique campaign speeches I examined to discover whether Barack Obama used a consistent rhetorical approach, the candidate rarely declaimed his own virtue, but instead repeatedly insisted that practical wisdom, virtue, and good will were qualities that he witnessed in the American people as a whole. Obama repeatedly used a powerful retelling of "the American story" as one grounded not in the personal ingenuity of independent-minded entrepreneurs, but instead in the progress-oriented collective advocacy of common sense activists. In this way, he cast the engine of American progress as the project of a collectivity of underdogs, a collectivity of which, on his telling, he was but an example. Told this way, he and his supporters fit squarely in the center of the narrative historiography of the American mythos, giving his political campaign an air of gravitas and insurgency that kept supporters and detractors alike riveted by the political phenomenon.

Deva Woodly, Friends of the Institute for Advanced Study Member in the School of Social Science, is Assistant Professor at the New School. Her research focuses on the impact of civic discourse on democratic practice, especially from the point of view of ordinary citizens, political advocates, and social movements.

The rise of Barack Obama during the 2008 campaign showed the power of public authority gained through persuasive rhetoric in sharp relief. And the fact that the then-candidate's rhetorical acumen was both a primary resource for his unlikely ascendance, as well as the favorite subject for recrimination from his political opponents, is telling. While the colloquial designation of a subject as "rhetorical" is meant to diminish the perception of its accuracy and importance, we know that, in practice, rhetoric is the only means by which communication with a mass public is possible. However, rhetoric is important not only because of the pragmatic limits of mass communication, but also, as Aristotle knew, because it is the art and heart of democratic persuasion, the process by which people make sense of and connect personally with a political world that they often do not view as central to their everyday lives.

One of the speeches that best exemplifies Obama's ethotic style was delivered not in a moment of triumph, but one of defeat. The candidate had lost the New Hampshire primary to Hillary Clinton, barely a week after an upset victory in the first-in-the-nation Iowa caucuses. In his concession speech, Obama was able to cast his loss in the frame of a familiar literary trope—the inevitable slump that afflicts the hero before the ultimate triumph that brings glory. However, Obama gave this trope a particularly democratic twist. He argued that it was not the twinkling of his own star that would lead his campaign to eventual victory, but instead the common sense activists who, in his version of "the American story," have always populated the American public, guiding the nation toward its highest aims.

> You know, a few weeks ago, no one imagined that we'd have accomplished what we did here tonight in New Hampshire. No one could have imagined it. For most of this campaign, we were far behind. We always knew our climb would be steep. But in record numbers, you came out, and you spoke up for change. And with your voices and your votes, you made it clear that at this moment, in this election, there is something happening in America.

Of course, the idea that *something* might be happening had already occurred to many people. It had been reported and speculated about in every news venue in the week intervening between the two primaries. Obama seemed to comprehend that although argument from *ethos* is about convincing the audience of one's own good character, the surest way to make such an argument convincing is not to declaim one's own virtue, but instead to reflect an understanding of the virtue of the audience who will judge. Or, as Aristotle explains, we are most kindly disposed toward "those who praise the presence of good qualities in others and especially the qualities that these people fear they do not really have." (1381b)

> There is something happening when men and women in Des Moines and Davenport, in Lebanon and Concord, come out in the snows of January to wait in lines that stretch block after block because they believe in what this country can be. There is something happening. There's something happening when Americans who are young in age and in spirit, who've never participated in politics before, turn out in numbers we have never seen because they know in their hearts that this time must be different. There's something happening when people vote not just for the party that they belong to, but the hopes that they hold in common. And whether we are rich or poor, black or white, Latino or Asian, whether we hail from Iowa or New Hampshire, Nevada or South Carolina, we are ready to take this country in a fundamentally new direction. That's what's happening in America right now; change is what's happening in America.

The discursive deftness of Obama's 2008 campaign discourse was such that many people came to believe fervently in Obama's own good character because he kept insisting that he believed in theirs. In the passage above, the candidate is able to convey his very practical and political need for the continued work of his supporters as an expression of a transcendent and ongoing necessity, not only or primarily to benefit himself, but instead to reinvigorate the civic vision, promise, and good judgment of "ordinary Americans" in the political process.

> We know the battle ahead will be long. But always remember that, no matter what obstacles stand in our way, nothing can stand in the way of the power of millions of voices calling for change. We have been told we cannot do this by a chorus of cynics. And they will only grow louder and more dissonant in the weeks and months to come. We've been asked to pause for a reality check. We've been warned against offering the people of this nation false hope. But in the unlikely story that is America, there has never been anything false about hope.

This passage is tuned to make the listener feel a part of a common struggle. It has an oppositional feel. Obama identifies a powerful and unnamed "they" who will stand in the way of the change that America, on his telling, presumably wants, while assuring his audience that the "they," though powerful, cannot triumph. He conveys that he knows this, not because he is a special political leader telling the audience about his own good qualities, but instead because he is a quintessential American, following, as are all his supporters, in the footsteps of those historical underdogs that we lionize in our national mythos: those that were savvy and brave enough to stand against the prevailing wisdom of their time and for the progress of the ages.

> For when we have faced down impossible odds, when we've been told we're not ready or that we shouldn't try or that we can't, generations of Americans have responded with a simple creed that sums up the spirit of a people: Yes, we can. Yes, we can. Yes, we can. It was a creed written into the founding documents that declared the destiny of a nation: Yes, we can. It was whispered by slaves and abolitionists as they blazed a trail towards freedom through the darkest of nights: Yes, we can. It was sung by immigrants as they struck

(Continued on page 17)

The (Bio)technological Sublime: From Nature to Technology and Back

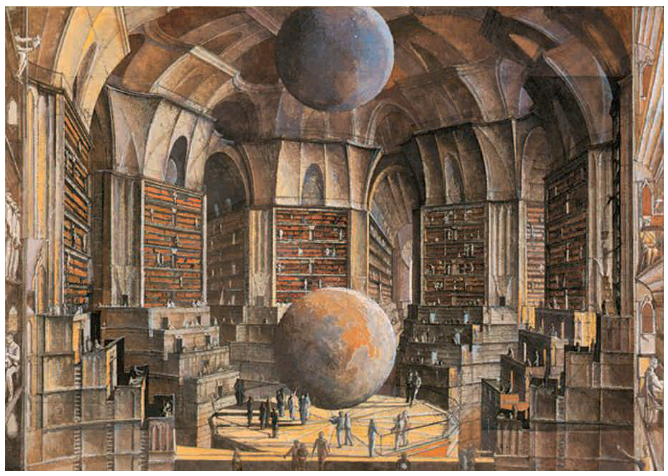
BY JOS DE MUL

Many things are awesome, but none more awesome than man. — Sophocles

Every once in a while, we experience something extraordinary. Such "awesome" experiences might happen in research, when we unexpectedly discover something really amazing, or when we come across a magnificent landscape, hear a piece of music that really moves us, or when we fall deeply in love. Traditionally, these kinds of extraordinary experiences are called "sublime." In the following, I will present some reflections on one particular kind of sublimity: the technological sublime.

Although the word "sublime" first appears in English in the fourteenth century, the notion goes back a long way. It is described in the Greek essay *Περὶ ὕψους*, written in the first century and—probably incorrectly—ascribed to Longinus. It was, however, not before the seventeenth and eighteenth centuries that the notion of the sublime started its victory march through European cultural history. In the period between the Baroque and Romanticism, the sublime became one of the key concepts in aesthetics, ethics, and even ontology.

Three characteristics of the modern sublime come to the fore. First, the word predominantly refers to natural phenomena with a divine ring, such as mountain landscapes, stormy seas, and starry night skies. The German philosopher Immanuel Kant distinguishes between mathematical and dynamic sublimity. The first is evoked by the immeasurable and colossal, pertaining to the idea of infinitude, surpassing all human imagination and understanding. The dynamic sublimity, on the other hand, confronts us with superior forces of nature, such as volcanic eruptions, earthquakes, or tsunamis. The latter experience of the sublime strikes us with our vulnerability.



La Salle des planètes *from Érik Desmazières's series of illustrations for Jorge Luis Borges's story "The Library of Babel," 1997–2001*

Second, the modern sublime is strongly contrasted to beauty. Beautiful things give us a pleasant feeling. They feed our hope that we are living in a harmonious and purposeful world. The sublime, on the other hand, is connected with experiences that upset our hopes for harmony, due to their unbounded, excessive, or chaotic character.

Third, although the experience of the immeasurable and potentially destructive forces of nature evokes unpleasant feelings, contemplating them from a safe distance (for example, by watching a painting of a stormy sea in a museum) is pleasurable as well. Sublime experience is highly ambivalent. The sublime evokes both awe and fear; attraction and repulsion melt into one ambiguous experience. Therefore, the sublime has been defined as "a pleasure mingled with horrors" (John Dennis), "delightful terror" (Edmund Burke), and an experience which induces "negative lust" (Kant).

Friedrich Schiller conceptualizes the sublime beyond the safe cocoon of aesthetic experience. He distinguishes between a reflexive experience of the sublime (be it mathematical or dynamic) and a practical encounter with the sublime. In his view, we can only experience the sublime when we actually collapse in a glorious battle against the superior powers of nature or military violence: *Groß kann man sich im Glück, erhaben nur im Unglück zeigen* (One may be great in times of good fortune, but one only can be sublime in times of misfortune).

With this transformation, Schiller—impressed by the Jacobin terror following the French Revolution and the connected rediscovery of Greek tragedy, with its emphasis on the *deinon* (awesome) character of man—paved the way to the modern experience of the technological sublime.

Through the nineteenth and twentieth centuries, the main site for the ambiguous experience of sublimity gradually shifts from nature to technology. This transformation is closely connected with two major developments in Western society: the secularization and disenchantment of nature, and the spectacular growth of the natural sciences and technology. Nature increasingly becomes the object of technical control.

As David Nye has documented in great detail in his book *American Technological Sublime* (MIT Press, 1994), during the twentieth century, the American experience of the natural sublime was gradually complemented and even surpassed by the technological sublime: the sublimity of the factory, the skyscraper, the metropolis, automobility, aviation, and space travel.

But of all the twentieth-century technologies the computer—the universal machine—is perhaps the most sublime technology. In a world in which the computer has become the dominant technology, everything—atoms, genes, texts, organizations—becomes a relational database, a collection of (re)combinatory elements. Keeping Kant's distinction between the mathematical and the dynamical sublime in mind, we might also distinguish between mathematical and dynamic sublimity in computer technologies.

The mathematical sublime in the age of the computer manifests itself in combinatorial explosions and multiverses. For a literary expression of the mathematical sublime, we may think of Jorge Luis Borges's "The Library of Babel," which contains all possible different books made out of the twenty-five symbols of the Spanish alphabet, a hyper-astronomical number compared to which the number of atoms in our universe is negligible.

We encounter the dynamic sublime not only in nuclear power but also in the practical applications of biological databases being used in the life sciences and various biotechnologies. Considering the hyper-astronomical number of possible recombinations of the three billion nucleotides that not only can be simulated *in silico* but are increasingly realized *in vitro* and *in vivo*, we get a first glimpse of the dynamic sublime in the age of biotechnology. Of course, there are many—physical, chemical, biological, and historical—constraints on the number that actually can be realized, but even then the number and possible impact is sublime.

What is both fascinating and uncanny in all this is that, in this process, we witness a fascinating trading of places of nature and technology. While nature is increasingly controlled and governed by man and turned into a cultural category, our technological environment becomes so complex and uncontrollable that we start to relate to it as a force on its own. With the aid of techniques such as genetic modification and attempts to synthesize life from scratch—the holy grail of synthetic biology—we are creating a "next nature" that possesses and increasingly develops its own intentionality and agenda.

Here the pendulum is swinging back: whereas the sublime transformed from a natural to a technological category in the twentieth century, in the twenty-first century, we are witnessing the technological sublime becoming a natural phenomenon again. And like the holy in premodern times, the biotechnological sublime is Janus-faced: it reflects both our hope for secular salvation (production of fuel and food, cure of diseases, transhumanist dreams of immortality) and our fear of its uncontrollable, destructive power. Should we exercise constraint with regard to the biotechnological sublime or rather affirm it in blind hope, as we have done since Prometheus? Or should we rather say that *Homo sapiens*, the species that is artificial by nature, for that reason, has been denied the choice *not* to be technological.

Not so much a conclusion, but rather as a thought for consideration, I will close with the following words of Ronald Dworkin: "Playing God is indeed playing with fire. But that is what we mortals have done since Prometheus, the patron saint of dangerous discovery. We play with fire and take the consequences, because the alternative is cowardice in the face of the unknown." ■

Jos de Mul, a Visitor in the Program in Interdisciplinary Studies and Professor of Philosophical Anthropology at Erasmus University Rotterdam, presented a version of this essay as an After Hours Conversation at the Institute on October 4, 2012. An extended version will be published as "The (Bio)technological Sublime" in Diogenes *233–34 (Spring 2013). On this and related topics, see also Jos de Mul,* Destiny Domesticated: The Rebirth of Tragedy Out of the Spirit of Technology *(State University of New York Press, Autumn 2013).*

REVIVING RHETORIC *(Continued from page 16)*

> out from distant shores and pioneers who pushed westward against an unforgiving wilderness: Yes, we can. It was the call of workers who organized, women who reached for the ballot, a president who chose the moon as our new frontier, and a king who took us to the mountaintop and pointed the way to the promised land: Yes, we can, to justice and equality. Yes, we can, to opportunity and prosperity. Yes, we can heal this nation. Yes, we can repair this world. Yes, we can.

Here, Obama makes political change sound effort-filled but achievable, even natural. In addition, the poetic historical sweep, which takes into account an arguably ideologically incoherent set of change agents, is overlaid with the sheen of coherent nobility. America, he communicates, is a nation built by audacious underdogs who could not be put off by the powerful and the petty. In this way, Obama was able to invert the usual relationships between official power and insurgent challenge. He argues that difference and resistance are the unifying themes of the American experience and recharacterizes losing as a necessary, transitory test before an eventual exultation that is not only possible but nearly inevitable.

The frequent criticism of Barack Obama as "merely rhetorical" rather than substantive, as if discursive power is somehow not "real," is a neat encapsulation of the reason why it is so important to take rhetoric seriously in the study of politics, particularly for those of us interested in how political underdogs can make credible challenges to status quo arrangements of power and privilege. Barack Obama's campaign was an innovative version of institutional electoral politics and not a social movement, but the way that the candidate used rhetoric to claim a credible space at the political table is nevertheless instructive. Social movements, like candidates, benefit from a combination of organizational strength and rhetorical savvy. A popular discourse on movement goals and issues, even when there is political backlash, can make all the difference in whether a political challenger has a chance against those who begin the contest with more resources and power. Public discussion tends to enlarge the scope of conflict, and as E. E. Schattschneider observed, the publicity of the competition is what gives the underdog a fighting chance. In this way, rhetoric can be used as a resource that helps to level the playing field in political contests. ■

* Lymari Morales, "Americans More Tuned in Than Ever to Political News," Gallup (September 22, 2008).

A Fortuitous Discovery: An Early Manuscript by Erwin Panofsky Reappears in Munich

By Uta Nitschke-Joseph

In June 2012, an early work by Erwin Panofsky (1892–1968) was found in an armored cabinet in the basement of the Zentralinstitut für Kunstgeschichte in Munich. The study, "Die Gestaltungsprincipien Michelangelos, Besonders in ihrem Verhältnis zu denen Raffaels" ("Michelangelo's Principles of Style, Especially in Relation to Those of Raphael"), fills a gap within the extensive list of publications of one of the most eminent art historians of the twentieth century.

GERDA PANOFSKY

Erwin Panofsky, Professor (1935–62) and Professor Emeritus (1962–68) in the School of Historical Studies

Many knew about it, many looked for it, but no one was able to find it. Assumed lost in the bombing of Hamburg during World War II, Panofsky's manuscript on Michelangelo, written at the end of the second decade of the twentieth century, had become a legend, a mystery that, as the years went by, was less and less likely to be solved. Not even the correct title had been preserved. All that was known was that during the late spring of 1920, Panofsky's study had been accepted as his *Habilitation* thesis by the Faculty of Philosophy of the University of Hamburg, and after the required additional examination, Panofsky had received the *venia legendi*. Then the manuscript vanished, until now, when it reappeared in the most unlikely place, a safe in the basement of what used to be the administration building of the National Socialist German Workers' Party in Munich. What had happened? This account attempts to reconstruct the history of the manuscript based on information gathered from publications like the *Erwin Panofsky Korrespondenz 1910–1968* (ed. Dieter Wuttke, 5 vols. [Wiesbaden, 2001–11]), Horst Bredekamp's article "Ex nihilo: Panofsky's *Habilitation*" (in *Erwin Panofsky: Beiträge des Symposions Hamburg 1992*, ed. Bruno Reudenbach [Berlin, 1994], 31–51), and recent newspaper articles as well as critical details provided by Gerda Panofsky, Erwin's second wife and widow, and Stephan Klingen from the Zentralinstitut.

There is no evidence illuminating the impulse that led to the selection of the *Habilitation*'s topic other than the lectures and seminars on Michelangelo that Panofsky had attended at the Königliche Friedrich-Wilhelms (now Humboldt)- Universität in Berlin; nor is it known when exactly Panofsky began working on the manuscript. After earning his doctoral degree at the University of Freiburg in July 1914, he spent the next few years publishing his dissertation and writing several articles. At the outbreak of World War I, he had been drafted into the army, but owing to a riding accident soon afterward, he was declared unfit for service at the front. In the spring of 1917, however, he was deemed fit for duty at the home front and was assigned a governmental job in Kassel and then in Berlin with the authority distributing coal to the civilian population. The demobilization finally freed him from military service in January 1919.

While working for the distribution authority in Berlin in December 1918, he put in an application for *Habilitation* at the University of Heidelberg. As a *Habilitation* thesis he offered either to present "Dürers Kunsttheorie, vornehmlich in ihrem Verhältnis zur Kunsttheorie der Italiener," which had been published in 1915 and was the expanded version of his dissertation (only pages 122–180 had been submitted as his dissertation thesis in Freiburg/Breisgau), or the heretofore unpublished study on the "Westbau des Doms zu Minden" (later published in *Repertorium für Kunstwissenschaft*, vol. 42 [1920], 41–77). In case neither work would be accepted, he proposed to extract a partial topic from his current research and develop it into a larger, more extensive study. Three months later, on March 30, 1919 (his twenty-seventh birthday), he withdrew his application because of unexplained extraordinary circumstances. In August of the same year, he was working on a presumptive *Habilitation* for the University of Tübingen and hoped to travel to Southern Germany to present the finished thesis at the beginning of winter. It is not known if Panofsky had chosen to expand his study on the cathedral of Minden or if he had moved on to a different subject.

When, in December 1919, the Director of the Kunsthalle Hamburg, Gustav Pauli, asked him if he would be interested in lecturing on art history at the University of Hamburg, Panofsky emphasized in his response that in accepting he also meant to apply for his *Habilitation*. At this point, the process accelerated. In a letter addressed to the Faculty of Philosophy of the University of Hamburg, dated Berlin, March 11, 1920, Panofsky writes that after leaving the military he had concentrated on working mostly on the subject of Michelangelo's style and that he was submitting the completed first part of this project (whose second part he was to finish by the end of the year) with his application for *Habilitation*. Nine days later, Pauli informed Panofsky that he was reading his thesis. Obviously impressed by what he had seen so far, he encouraged Panofsky, in confidence, to rent the prospective apartment in Hamburg. Thereafter, the communication ceased for a period of almost three months, enough time for Panofsky to voice his concerns in a letter to Pauli stating that he had not yet heard anything officially from the university and asking advice on how best to proceed. His concerns, however, were unfounded. Pauli had presented his evaluation on May 10, 1920, to the mandated committee that had been formed for the *Habilitation* procedure. The other members, Max Lenz, Ernst Cassirer, and Otto Lauffer, concurred with Pauli's positive evaluation between May 25 and June 3. In a meeting of the Faculty of Philosophy on June 19, the approval was accepted and July 3 was decided upon as the date for Panofsky's *Probevorlesung*. This trial-lecture on the topic of "Die Entwicklung der Proportionslehre als Abbild der Stilentwicklung" (published 1921) completed the *Habilitation* process. Panofsky was awarded the *venia legendi* and was thus able to begin teaching in Hamburg.

It is around this time that the manuscript disappeared. The author mentioned his plans to edit the Michelangelo text once more in a letter to his wife Dora on July 3, 1920. More than forty years later, Egon Verheyen wrote to Panofsky inquiring about the thesis after seeing it cited in a footnote in an article by Gert van der Osten, then Director-in-chief of the Cologne Museums. Panofsky recalled the exchange with van der Osten and answered on January 28, 1964, "My 'Habilitationsschrift' was concerned with the stylistic principles of Michelangelo, seen against the background of the development of art from Egypt to Bernini […]. The original manuscript is lost […]." (*E. P. Korrespondenz*, vol. 5, 440).

Long before the manuscript was rediscovered or Panofsky's correspondence was published, Horst Bredekamp's 1992 lecture sought not only to give a detailed account of its early history, including a copy of Pauli's evaluation of the text—the only written testimony that had been preserved—but also set out to carefully search for traces of the content as well as examine if and where parts of it might have been incorporated into Panofsky's later publications. Pauli's evaluation mentioned neither the title nor the size of the work. The recently discovered manuscript finally provides these details: aside from the aforementioned title, we now know that it is comprised of 334 pages, of which about 50 percent is typewritten text, and the other half handwritten additions. According to Gerda Panofsky, the text was verifiably edited and expanded until at least the end of 1922. Written before the invention of the photocopy machine, this was the author's own and only copy, which he had labeled "Michelangelo I. Exemplar." It is possible that after the *Habilitation* procedure was completed the typescript had been returned to the author for final revisions.

Pauli's evaluation had previously allowed some insights into its content, in which Panofsky tries to define the uniqueness of Michelangelo's style by comparing his works with those from antiquity (including Egyptian art), the Quattrocento, his contemporary Raphael, and the Baroque. According to Panofsky, Michelangelo was not a predecessor of the Baroque; if anything he was perhaps a brother of the Baroque. It may seem surprising that Panofsky applied a method associated more with that of his teacher Heinrich Wölfflin, who used the history of style and motifs to analyze a work of art, an approach Panofsky had earlier criticized in his article "Das Problem des Stils in der bildenden Kunst" (1915). Yet, he had always highly respected Wölfflin. Moreover, the reemerged manuscript may also show that Panofsky did not cling literally to Wölfflin's principles, but that, according to Bredekamp, "he obviously highlighted Wölfflin's bipolar organized principles of style with a view of Michelangelo in their potential for conflict. This should not be seen by itself as an application of Wölfflin's method. It is an independent development" (interview in *Jewish Voice of Germany*, September 22, 2012).

What were Panofsky's plans for his *Habilitation* thesis? Bredekamp acknowledged that it is not rare to utilize a *Habilitation* thesis as a kind of quarry for other works and provided numerous examples demonstrating how Panofsky revisited the *Habilitation*'s thesis whenever his research focused on Michelangelo. Panofsky himself referred to his "Habilitationsschrift" "as a much too ambitious attempt" and while it had not been published, he stated he had incorporated some of its ideas in his later work.

Panofsky wrote for the last time about Michelangelo in the chapter "The Neoplatonic Movement and Michelangelo" of his *Studies in Iconology* (1939), the Mary Flexner Lectures he had given at Bryn Mawr College in 1937. A comparison of this publication with the rediscovered *Habilitation* thesis reveals similarities to the earlier work. Panofsky may have taken some notes with him when he left Germany in 1934 after all, because even his excellent memory would probably not have been able to retain so many details.

The *Habilitation* thesis itself had certainly been left behind in Germany. Panofsky spent the years until 1930 in the Hanseatic city teaching, writing, and developing the Institute of Art History at the University of Hamburg, and, at least until 1922, also revising and annotating his *Habilitation* thesis. From 1931 to 1933, he lectured alternate terms at Hamburg University and at New York University's Institute of Fine Arts. The Hamburg appointment came to an abrupt end on April 7, 1933, with the enactment of the Law for the Restoration of the Professional Civil Service (Gesetz zur Wiederherstellung des Berufsbeamtentums) that allowed tenured civil servants to be dismissed. Jews and political opponents could no longer serve as teachers, professors, judges, or in other government positions. Panofsky happened to be in New York at the time of the enactment of the law. Upon his return to Hamburg in May 1933, he decided to continue supervising the dissertations and oral exams of three of his Jewish graduate students who had almost completed their course work. However, he held these sessions not at the university—although his office and the art history seminar at the time were actually located at the Hamburger Kunsthalle—but at his private apartment. Thus, if his *Habilitation* thesis was in his room at the seminar, into which he refused to set foot, he never retrieved it. His official dismissal from the University of Hamburg occurred on June 28, 1933, to the chagrin of many members of the faculty and the students.

The manuscript's fate from then to its 2012 reemergence in Munich becomes even more enigmatic. Ludwig Heinrich Heydenreich belonged to the first generation of students who had studied with Panofsky in Hamburg and, thus, a special bond existed between teacher and his pupil that would last a lifetime. Heydenreich had completed his own *Habilitation* at the University of Hamburg in 1934, and, in the following years, he was entrusted with the management of the art history seminar before taking up a teaching position in Berlin in 1937. In 1943, he assumed the Directorship of the German Kunsthistorisches Institut in Florence and, after the war, he helped found the Zentralinstitut für Kunstgeschichte in Munich, becoming its first Director in 1947. He retired in 1970 and died in 1978. It was in the basement of this building that the manuscript was discovered. The building, erected in 1934–35, had served as the Nazi Party's headquarters and the safes had been used to store the party's countrywide membership cards. After World War II, it became the "Central Collecting Point," where American and German art historians worked on the collection, documentation, and restitution of artworks that had been confiscated or purchased by the Nazis.

ZENTRALINSTITUT FÜR KUNSTGESCHICHTE, MUNICH

Counter-clockwise from top: The basement, armored cabinet, and binder at the Zentralinstitut where Panofsky's manuscript on Michelangelo was found

At what point in time the manuscript was put into the armored cabinet together with other papers from Heydenreich's term as Director is not known. Its rediscovery was purely by chance, because nobody was looking for Panofsky's text in Munich. A few years ago, Gerda Panofsky began to work on a biography of the early years of her husband's life, covering the period between 1900 and 1920. To complete her research, she made one final attempt in June 2012 to search for the *Habilitation* thesis. Like everyone before her, she was looking in the most likely place, Hamburg. Her inquiry resulted in precise information about Panofsky's *Habilitation* process, but it also specified that the whereabouts of the thesis were unknown and that it was presumed that it had been destroyed during the bombing of Hamburg in 1943–44. In the middle of this exchange, Gerda Panofsky received an email from Munich with the subject-heading "Fund" (find), informing her of the discovery at the Zentralinstitut. She was stunned: Panofsky had no connection with Munich other than that he had studied there for a semester in 1911. For the scholars on the other side of the Atlantic, the discovery of the binder with the manuscript was no less astounding. According to Dr. Stephan Klingen, Head of the Photo Collection at the Zentralinstitut and the finder of the manuscript, there are about forty to fifty such safes in the building's basement. These had been reused after World War II by the various academic institutions that had moved into the building. For two of these safes, the keys had gone missing, and it was eventually decided to have them professionally cracked open. One of them turned out to be empty; the other was filled to the brim with material from Heydenreich's directorship. Panofsky's manuscript was not immediately noticed. Only a request by a French scholar researching Heydenreich's appearance at an event in France in 1940 (he had given a speech before German officers in Fontainebleau) prompted Klingen to look more thoroughly through the Heydenreich bequest, thus bringing Panofsky's manuscript to light. After a check of Panofsky's extensive bibliography, it became clear that the folder contained the art historian's long-lost *Habilitation* thesis.

The topic of Michelangelo was raised at least one more time in a letter exchange between Heydenreich and Panofsky. Heydenreich had come to St. Louis, Missouri, as a Visiting Professor in 1948, and, in December of the same year, he wrote to Panofsky in Princeton. In this as yet unpublished letter, he asked for a meeting, but in the next paragraph, without transition, he implores Panofsky to write his [*sic*] Michelangelo book, as only he could do it and thus must [*sic*] do it (a scan of the letter, courtesy of the Archives of American Art in Washington, D.C., was obtained by Gerda Panofsky). Panofsky in his response stated very clearly that even though he felt flattered to be asked to write the definitive Michelangelo monograph, he had now moved on to other subjects. In February 1949, Heydenreich did visit the Panofskys in Princeton for a weekend as their houseguest, and he returned once more in the spring of the same year.

In another curious twist of events, Panofsky found himself, thirty-three years later, once again under the same roof as his *Habilitation* thesis. In July 1967, he came to the Bavarian capital to be awarded the Orden Pour le Mérite. Heydenreich, then still the Director, was instrumental in arranging the ceremony at the Zentralinstitut and actually placed the medal around Panofsky's neck. Panofsky spoke fondly of his former student in his acceptance speech.

Many questions concerning the manuscript and its peculiar history cannot be answered satisfactorily until more evidence is discovered and the text is available. Did Panofsky indeed abandon his *Habilitation* thesis and its scholarly method as Willibald Sauerländer, who succeeded Heydenreich as Director of the Zentralinstitut, suggested in the *Süddeutsche Zeitung* on September 6, 2012? Moreover, the whereabouts of the manuscript between 1934 and 2012 as well as how and when Ludwig Heydenreich came into the possession of it will perhaps forever remain a mystery.

After the long-lost manuscript's convoluted odyssey, a sense of continuity soon will be restored. In 1914, Erwin Panofsky's dissertation thesis was printed in Berlin by the Georg Reimer Verlag, one of De Gruyter's founding publishing houses. A century later, in 2014, his *Habilitation* thesis (edited by Gerda Panofsky) will be published by the same company. The manuscript's extraordinary journey, for now, has reached its final destination. ■

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AMIAS Elects Officers and Seven New Board Members

Steven A. Mansbach, an art historian from the University of Maryland, was elected President of the Association of Members of the Institute for Advanced Study (AMIAS) at its December 2012 Board of Trustees meeting. Mansbach succeeds Melvyn B. Nathanson, who served as Board President since 1998. Also elected were Kristen Ghodsee of Bowdoin College as secretary and Fouad Masrieh as treasurer.

The AMIAS membership, comprising current and former Institute scholars, elected seven Trustees to the class of 2015. Elected from the School of Social Science is Adam Ashforth, former Visiting Associate Professor at the Institute and current Professor in Afroamerican and African Studies at the University of Michigan. Joan Breton Connelly, former School of Historical Studies Member and current Professor of Classics and Art History at New York University and Director of the Yeronisos Island Excavations in Cyprus, also was elected. Two former School of Mathematics scholars were elected—William A. Casselman from the University of British Columbia and Maria Chudnovsky from Columbia University. Former Members from the School of Natural Sciences elected were Paul A. Hanle, President and Chief Executive Officer of Climate Central, and Andrew MacFadyen, an astrophysicist from New York University. The membership also elected its first Trustee from the Institute's Simons Center for Systems Biology, Raul Rabadan, Assistant Professor in Biomedical Informatics at the Columbia University College of Physicians and Surgeons.

The Trustee vacancies were created when six long-serving Board members stepped down, including mathematician Murray Gerstenhaber, who, in 1973, along with nine other Institute Members, founded AMIAS. Also rotating off of the Board are Herbert J. Bernstein, George E. Marcus, Melvyn Nathanson, Burt A. Ovrut, and William L. Pressly.

Two AMIAS Board meetings are scheduled for 2013. The May 10 meeting will include an AMIAS lecture by Nadia L. Zakamska, former Member in the School of Natural Sciences and current Assistant Professor of Astrophysics at Johns Hopkins University. The title of the talk is "Gone with the Wind: Black Holes and Their Gusty Influence on the Birth of Galaxies." This talk was originally scheduled in conjunction with the November 2012 AMIAS Annual Meeting of the Membership that was canceled due to Hurricane Sandy.

The fall 2013 Board meeting and the Annual Meeting of the Membership will highlight the 40th anniversary of the founding of AMIAS. All AMIAS members are invited to the November 8 celebration, which will include several lectures, followed by an AMIAS dinner. Invitations will be sent to the membership in late spring. For further information on AMIAS or on its 40th anniversary celebration, please refer to the AMIAS website, www.ias.edu/people/amias, or contact Member/Visitor Liaison Linda Cooper at llg@ias.edu. ■